

# METALLURGIA

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## Powder Metallurgy Education and Tomorrow

**I**N any review of papers on powder metallurgy published in this country it will be found that the proportion reporting actual work done here is very small while the majority of such papers will be reprints of communications which have already appeared in other countries. This does not mean that powder metallurgy is not finding application in this country, nor does it indicate lack of interest in the subject here. It does show that there are comparatively few powder metallurgists working here, and, more important still, that the subject does not find favour in the universities or technical colleges where training and tuition in metallurgy is given. It is, in fact, true that nowhere in this country is it possible to attend lectures or laboratory courses in powder metallurgy. This is a very serious matter for this country, and one that calls for much more consideration than it has hitherto received. Powder metallurgy, as yet, cannot claim to be of equal importance with certain other branches of metallurgy, but there is real and rapidly increasing interest in its possibilities, and there is little doubt that it will play an important part in the industrial development of the near future. So far as this country is concerned, we shall be gravely handicapped because there will be no supply of men or women trained in powder metallurgy, and it is quite impossible to improvise experience and knowledge in a subject so fundamentally different from ordinary metallurgy.

Already many firms and organisations are inquiring after personnel trained in powder metallurgy in order to commence investigating possibilities in their own particular spheres. No such personnel is available and as a result there have already been cases where a promising project has had to be relinquished, or at least postponed indefinitely because trained personnel were unavailable.

It does not require much knowledge to realise that in a subject which is different in so many fundamental directions from existing practice as is powder metallurgy, lack of training and experience will almost inevitably result in loss of money, material, time and opportunity. On the other hand, the subject has received rather good deal of publicity and so has aroused a good deal of curiosity and interest. Added to this, there have appeared some rather highly coloured claims as to what has been achieved in other countries, and, not unnaturally, English manufacturers feel that

they would like to try out some possibilities for themselves. Certain aspects of powder metallurgy do hold out attractive possibilities, especially in cases where mass production is the rule. We hear, for example, of articles being turned out by thousands an hour, of cases where in place of a 60% waste through machining, parts can be produced without any waste at all, at a higher production rate and having very much better physical properties and closer tolerances. Then, too, powder metallurgy can handle combinations that are metallurgically impossible by other methods, such as tungsten-copper, molybdenum-silver, and the like. There are also the many possibilities of porous metals in industry which have as yet received application in only the most obvious directions. The fact that porosity can be controlled over a wide range and yet within comparatively narrow dimensional limits so far as the actual pores are concerned, opens up quite a number of attractive developments that might well repay the costs of investigation. The mention of these few directions by no means exhausts the practical applications of powder metallurgy that are being made already both in this country and elsewhere, nor does it intimate the important developments that have taken place here during the war years. Notwithstanding these developments and the many applications of powder metallurgy which do flourish here to-day, we are still not only lamentably, but perilously short of any real educational facilities which would provide us with personnel trained in powder metallurgy.

For a moment it may be useful to refer to the United States of America, for we in this country are perhaps in closer touch with them than with any other foreign country; they are allies, and they speak our tongue. In the United States to-day there is organised tuition in powder metallurgy in several of their important institutes of technology, there are laboratory courses to supplement lectures, there are other lectures subsidised by the United States Government, and also by State Legislations. In the last three years there have been several important symposia, some held under the auspices of the world-renowned Massachusetts Institute of Technology, another last year sponsored by the American Society for Testing Materials. There has already been formed a Powdered Metals Institute whose most direct and important function is to advise United States Government and other departments on all matters appertaining to powder metallurgy and to bring to the notice of such departments directions in which powder metallurgy can be of direct service to the United States war effort. This Institute was formed

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

in 1942 by 12 companies using powder metallurgy processes, and their view of their province is expressed in their own words as "to serve as an advisory council in the Army and Navy in adapting powder metallurgy to war production." A further indication of United States interest and progress is the publication of the first papers presented before the Symposium on Powder Metallurgy, held in 1940 and 1941, under the auspices of M.I.T., edited by John Wulff and sponsored by the American Society for Metals, providing the best collection of papers available on the subject and an admirable commentary on American practice. Next came the publication of "A Course in Powder Metallurgy," by Walter J. Baëza, a book intended as a laboratory companion to the student attending a course of lectures on powder metallurgy. As against all this, we, in this country, have the book on "The Principles of Powder Metallurgy," by Dr. W. D. Jones, and a few papers mainly of a general character. We have no organised courses of instruction at any recognised educational centre.

This is all the more remarkable, because powder metallurgy is not by any means neglected in this country, nor are we seriously behind other countries in certain very important applications and there is no lack of interest in the subject not only among firms actually engaged in the metal industry, but also among many large firms engaged in various engineering enterprises. As might be expected, the well-known examples of applied powder metallurgy, the porous bearing, the steel-backed bearings used in the aeronautical and the automobile industries, the friction plates for heavy duty brakes and clutches, the valuable, indeed unique, metal combination used for electrical contacts; these and other applications have started engineers and others thinking of newer and wider uses to which powdered metals can be put. As a result, there are a really large number of engineers who desire information not only on the possibilities of powder metallurgy, but urgently desire to make a start, however small, towards realising some of the possibilities they see before them, and for that purpose want people with some experience and training in powder metallurgy. In this they are unquestionably right, for there is no field in which it is easier to waste a tremendous amount of time and money than in experimenting without previous experience and in attempting even the simplest operations in powder metallurgy without knowing something of the subject. To emphasise this, it may be said that it is a simple matter to name, say, 50 different applications of powder metallurgy, and each one of those applications will call for its own particular conditions, experience, methods and specifications. Moreover, it cannot be guaranteed, nor is it even likely that experience in one field will be of much assistance in another. What is of fundamental importance is a comprehensive and sound knowledge of the methods of preparation and the properties of metal powders, a full realisation of the importance of particle shape, size and distribution, experience and understanding of the plant used in pressing and sintering, and of the behaviour of powders under such treatment and of the factors which control and determine that behaviour. That is a short statement of what should be added to the normal training of a metallurgist if success is to be attained in the control of handling of powder metallurgical operations. It is difficult, sometimes almost impossible, to obtain recognition of the essential

differences that exist between normal metallurgical practice and that of powder metallurgy. It has been said that it is a simple matter to pick up the necessary experience in a few hours, or to obtain the rudiments in a couple of lectures or so. This is at once a costly and a dangerous doctrine. There are few subjects in which the saying that a little knowledge is a dangerous thing is truer or more likely to prove exceedingly expensive than in powder metallurgy.

In view of the possibilities which the future holds out to us it is to be hoped that the importance of educational facilities for powder metallurgy will not continue to be overlooked. There are schools of metallurgy at most of our universities, and tuition is given in the subject at a number of technical colleges. There should be organised courses available covering lectures and laboratory work at least at two important centres for a beginning, and later at every university where metallurgy is a subject. We want schools of powder metallurgy in this country at least equal to those now in being in the United States, in Germany, Japan and Russia, and we want them as quickly as possible.

## Iron and Steel Research

AT their meeting on March 21, the Council of the British Iron and Steel Federation approved a scheme which had been prepared by a Committee set up by Sir James Lithgow, Bt., M.C. (the outgoing president, who was chairman of the Committee in question) for the formation of the British Iron and Steel Research Association, which will take over the work of the Iron and Steel Industrial Research Council. The constitution of the new Research Association provides for collaboration with the Iron and Steel Institute, with the right of nomination of members of the Council of the new Association. It is understood that these will be scientists not connected with the industry, but engaged in fields of work related to the work of the Association. The Federation will nominate members who will represent the different departments of the industry—scientific, technological and management.

The present Research Council developed out of a Fuel Economy Committee established in 1924, and has now become one of the largest and leading collective research organisations in the country. Heretofore it has been a Standing Committee of the Federation, but a report on the work of the Research Council by the Department of Scientific and Industrial Research (October, 1942), which bore high testimony both to the scope and to the quality of the work which had been carried out under the direction of the Council, also recommended that it had now reached a stage where it was desirable that its work should be transferred to an autonomous research association under the aegis of the Federation and financed by it, to ensure that research becomes an activity of the whole industry and not merely a service rendered to it.

The scheme adopted provides for an annual expenditure of any amount which the Council of the Research Association may find necessary for the work required; and authority has been given to the Association to expend in the first instance up to £250,000 annually without further reference for the approval of the Federation. In the meantime, the Iron and Steel Industrial Research Council is continuing to direct the large range of research which it has in progress.



# The Deposition of Hard-Facing Alloys by Welding

By P. L. Pocock, A.M.Inst.W., M.I.S.Inst.

*The value of hard facing is increasingly appreciated, largely as a result of developments in materials and in the technique of welding them to suitable base materials required to resist wear, corrosion or both. Many methods of producing hard surfaces are used, in this article the author confines his attention to the fusion welding of hard alloys.*

**T**HE main purpose of applying hard facing is to reduce the wear of a particular part or piece of a machine that is subjected to heavier service than the remainder of the machine, and by prolonging the serviceable life of this part the machine can remain in operation for a longer period, with a substantial reduction in maintenance and idle time costs. In addition to increasing the service life of a particular key part, the hard facing applied has a low coefficient of friction, is resistant to corrosion, and can be applied successfully to cheaper base metals. Hard-faced parts will outwear the normal base materials used from 2 to 30 times, depending upon the type of hard-facing alloys used.

Many ferrous components must be strong and tough because of their design or function and generally a compromise between hardness and toughness must be accepted. With parts designed for hard-facing, however, the body or parent metal can be of steel expressly suited for strength requirements and resistance to shock; the wearing surfaces being subsequently hard-faced with a suitable wear-resistant material to form composite components which possess both strength and hardness according to function of a particular part. Often plain medium-carbon steel is used or low-alloy steels may be required for the base material, whichever satisfy the necessary strength and resistance to shock.

Various materials are used to provide hard-wearing surfaces on parts of components required to resist abrasion, thus, low-alloy steels containing either manganese, chromium, nickel, tungsten, molybdenum, or vanadium, with 0.3 to 0.6% carbon and alloying elements approximating to 5%, may satisfy the service conditions; but usually harder materials are required, such as high alloy steels of manganese, tungsten, cobalt, molybdenum, or nickel, together with high chromium, the alloying elements exceeding 10%; non-ferrous alloys of cobalt, chromium and tungsten, which have the property of red hardness; and carbides of boron, tungsten, tantalum or titanium, which have a hardness range between 8.5 and 8.9 on the Moh scale of hardness, and which retain their hardness well at elevated temperatures. The order of toughness of these materials is approximately the opposite of wear resistance, and for this reason no one material can be applied successfully for every purpose. Tungsten carbide, for instance, may be the most suitable for use where friction is the deciding factor, providing little or no impact is encountered; on the other hand, for smooth-bearing surfaces or corrosion resistance the cobalt-base non-ferrous alloys have much in their favour.

The cobalt-chromium-tungsten group of alloys contain little or no iron, but they may contain vanadium or



Rolling mill guides hard-faced with "Stellite" are claimed to last ten times as long as untreated guides.

molybdenum. Stellite is in this group as well as several other proprietary alloys. All are characterised by high resistance to acids and alkalis, low coefficient of friction, and high hardness up to 700° C. The melting point of these alloys is about 1,300° C., while the hardness varies from 416 to 650 Brinell. The carbides have the highest hardness, as, for instance, the granular tungsten carbide used for this purpose, but the melting temperature is about 2,800° C., and it can only be applied by means of the carbon arc.

## Base Materials

Before discussing the application of these hard-facing materials a brief reference should be made to the base materials used for components which require to be hard-faced. Most steels can be readily hard-faced, but those containing 0.50% carbon and over usually must be heat-treated, and the hard-facing of high-speed steel is unsatisfactory. Low alloy and stainless steels, grey cast iron, alloy cast iron, and nickel base alloys are successfully hard faced, but brass, bronze, copper and aluminium alloys are difficult or impossible to hard face by welding because of their relative low melting points. The difficulty with these latter materials is overcome by the introduction of hard metal inserts with which we are not concerned in this discussion.

### Treatment of Component to be Hard-Faced

The successful application of the hard-facing depends largely upon the preliminary treatment of the component to which it is applied. All loose scale, dirt, rust, or other foreign substances should be removed from the areas to be hard-faced, preferably by grinding or machining. The base metal should be clean. When application is to be made to a groove, corner or recess, it is preferable to have all corners well rounded, otherwise local overheating of the base metal may result. Where only a small section of a component is to be hard-faced, a suitable shallow recess, groove or indentation to receive the hard-facing metal may be prepared either mechanically or with the oxy-acetylene blowpipe.

It is generally recognised that preheating is often advisable in most welding operations, and the same general rules apply before hard-facing. Parts are preheated in those cases where the application of hard-facing would otherwise cause them to warp, or where both time and welding heating medium can be saved by preheating. Usually, steels containing more than 0.5% carbon should be preheated. The larger the surface to be hard-faced, the higher the preheating temperature must be to avoid cracks. In nearly all circumstances the base metal should be preheated to between 200° and 800° C., depending on size and sensitivity to hardening. Usually, preheating in a furnace is best and, after hard-facing, it is important to cool slowly after reheating to 700°-800° C.

An important factor is the preparation of the base material to ensure a satisfactory bond for the hard-facing metal or alloy. Thus, for instance, correct procedure is indicated in Fig. 1; that at A shows the method used if the surface applied is to be subjected to shock in service, such as in the case of a die; that at B is the normal form of preparation for general service conditions; while that shown in C is the usual method when the hard-facing is to be applied to longitudinal areas. Whichever method is employed, care should be taken to obviate sharp corners

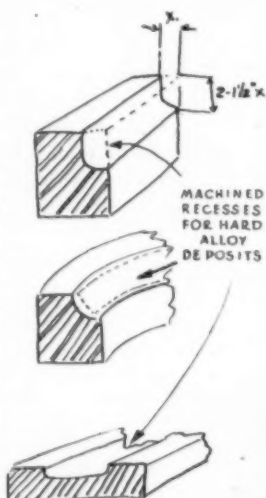
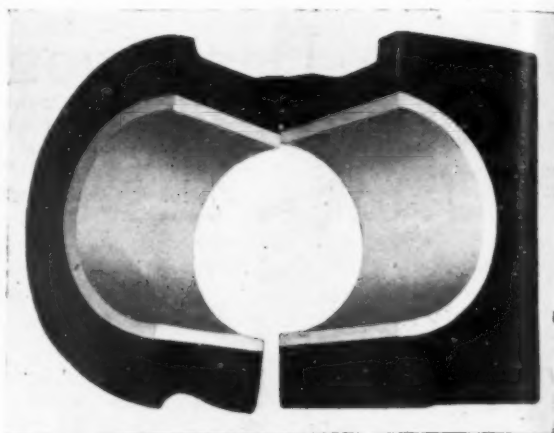


Fig. 1.—Preparation of components to receive hard facing material.

### Welding Processes

Hard-facing metals and alloys are applied by either electric or oxy-acetylene welding processes, although non-ferrous alloys are best applied by means of the oxy-acetylene process. Generally, this latter process permits close control over the operation and produces a smooth deposit. An exception to this general recommendation for the use of the oxy-acetylene process is the non-ferrous hard-facing alloys deposited on manganese steel. For such base metal arc welding is generally preferred, since the absorption of heat by the base metal is not so great by this process. For heavy parts, the



Cement mill bearing faced with "Stellite" increased service life to three years, compared with three months previously.

arc process, in many cases, can be used without preheating, as, with large areas, the possibilities of distortion are not so great. The electric arc can also be used with advantage for heavy parts which do not require finishing operations to the deposited metal, and, as stated earlier, it is preferable for the hard-facing carbides.

With the oxy-acetylene process, particles of scale and foreign matter are easily eliminated and edges and corners can be readily formed. Other advantages of this process include low loss for expensive alloys by vaporisation or spattering, close control of the oxidising or reducing conditions of the atmosphere surrounding the molten metal, and accurate control over the degree of penetration of hard-facing alloy in the base metal. This latter advantage is of importance, especially with respect to the application of certain classes of hard-facing materials, some of which should be puddled, while others are flowed on to the base material at a "sweating" heat. The oxy-acetylene process offers facilities for producing either condition at the will of the operator.

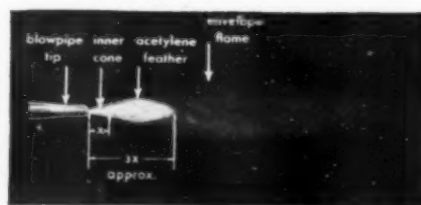


Fig. 2.—Showing the relative size of the cone and flame.

### Oxy-Acetylene Welding Practice

The practice adopted with the oxy-acetylene flame varies with the nature of the metal being deposited. In the practice of depositing from the cobalt-chromium-tungsten hard-facing rods, for instance, the blowpipe should be adjusted to a carburising flame with the tip of the outer cone extending almost three times the length of the inner cone. A tip sufficiently large to hold the heat in the body metal should be used; usually the blowpipe size is larger than that used for welding mild steel of the same thickness as the component to



Punching and drawing dies faced with "Stellite." Experience has shown that steel dies have a service life of approximately 150,000 components per grind, while the hard-faced dies give 600,000 per grind.

which the hard-facing alloy is to be applied. The nozzles sizes and gas pressure for various metal thickness are given in the accompanying table:—

EQUIVALENT TIP SIZES.

Oxweld W. 15 and W. 17, L.P.	Can. Liquid Air, L.P.	Oxygen Pressure on the Regulator (in lbs.).	British Oxygen.		British Industrial Gases.	
			L.P.	H.P.	L.P.	H.P.
3	1	15	4	225	4	2
5	3	15	4	225	4	2
6	4	15	6	350	6	5
7	5	15	6	350	6	5
8	6	18	6	350	6	5
9	7	18	12	1,500	12	10
10	8	18	12	1,500	12	10

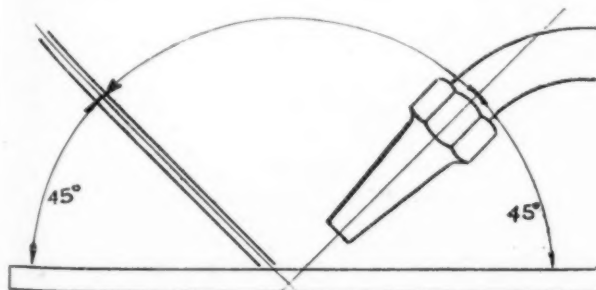


Fig. 3.—Showing the angles of rod and nozzle.

Without an excess of acetylene the cobalt-chromium-tungsten alloys tend to spheroidise and pile up, and become porous instead of running freely and making a uniform and smooth deposit. The relative size of the cone of the flame is shown in Fig. 2. The angles of blowpipe and the hard alloy rod should be as shown in Fig. 3, and the flame should be held so that the inner white cone is about  $\frac{1}{4}$  in. away from the work and the feather of the acetylene envelops the rod and maintains the area in a sweated condition.

Before the hard alloy can be applied to the base material the surface to which it is to be welded must be brought to a sweated condition by the acetylene flame. When a mild steel base material is used it takes

up carbon from the flame, and a thin surface film of higher carbon steel is formed having a lower fusing point, hence this film appears to "sweat" before any measurable part of the base metal is heated to its real melting range. When this occurs, the rod should be held as indicated in Fig. 4, and as the alloy melts from the rod it will spread freely over the sweating surface. Any scale encountered or formed in the course of the work should be floated off by manipulation of the flame to avoid pinholes in the deposit.

The importance of getting the surface of the base metal in a sweated condition to permit easy flow of the deposit is emphasised in Fig. 5. It is noteworthy, too, that the very thin original sweated layer forming the bond between the base metal and the hard-facing alloy possesses greater strength and toughness than either the base metal or the hard-facing alloy, due to the inter-alloying of the two metals in this thin layer.

As the rod melts in the process a puddle of hard alloy will form in contact with the base material and will spread over the sweated area, forming a clean deposit. Should the hard alloy not spread freely the base material is too cold and will require reheating to a sweating condition. The blowpipe flame should continue to be played over the area of the puddle and as the blowpipe is moved forward the hard alloy should be added at intervals to build up the required thickness of deposit. The rod should be kept in the envelope of the flame. The hard alloy should be coaxed along in the direction of travel by the movement of the blowpipe and not by stirring the puddle with the rod, rather should the application of the rod reproduce a gentle brushing action, taking care to disturb the thin layer of base metal as

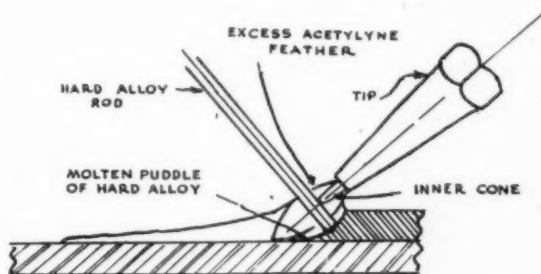


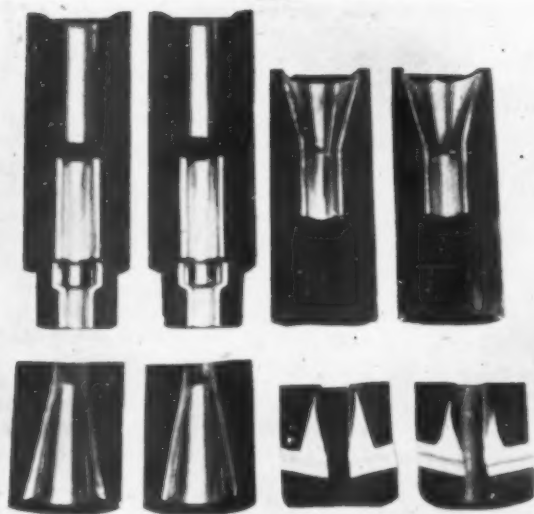
Fig. 4.—The normal leftward method of depositing.

little as possible, otherwise iron will combine with the hard alloy and dilute its properties, subsequently affecting its life and efficiency.

Ordinarily, the leftward method of progress is used, as in Fig. 4, but in cases where the base metal scales badly the rightward method of progress may be applied as shown in Fig. 5.

After the hard alloy has been deposited the component should be allowed to cool very slowly to prevent it cracking and to reduce undue stresses; for this purpose it may be bedded into any insulating material available, or, as advised earlier, the best method is to reheat slowly in a furnace and then allowing the component to cool with the furnace.





Clamping dies, former dies and drill chucks hard faced with "Stellite" give a life 5 times that of steel dies.

### Electric Arc Process

The penetration is somewhat deeper with the electric arc than with the oxy-acetylene process, in consequence interalloying takes place to a greater extent, although it can be kept at a minimum by careful control. The arc process is generally more economical for covering large areas, and it is frequently employed if rough surfaces and some cracking or checking of the hard-facing metal are not objectionable. The preparation of the component to be hard-faced should be the same as when using the oxy-acetylene method.

Either direct or alternating current may be used, and with direct current bare rods may be employed, but

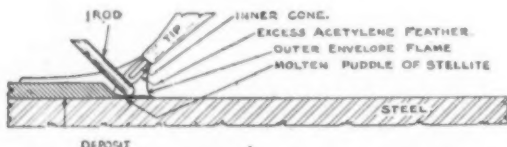


Fig. 6.—The backhand method of depositing.

where possible it is advisable to use those that are flux-coated. A smooth bead is more likely with the coated rods and, generally, there is less likelihood of cracks and of porosity. When using alternating current for the cobalt-chromium-tungsten hard-facing alloys the positive pole should be used for the alloy electrode.

In general, the current value should be slightly higher than is used for mild steel of similar section. For the cobalt-chromium-tungsten alloys the operation is similar to that when arc welding mild steel, and should follow the same general rules: the electrode to be held nearly vertical; the arc maintained at approximately  $\frac{1}{8}$ – $\frac{3}{16}$  in. from the work surface, and extreme care must be taken to keep the arc moving with a swinging movement to prevent deep penetration; this latter point is most important. If it is necessary to deposit more than one bead to cover the required area, the

first layer should be thoroughly wire-brushed and each successive layer should overlay the previous one,

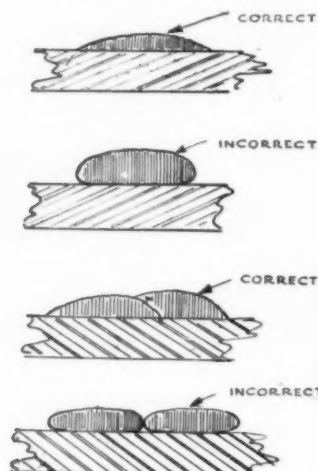


Fig. 5.—The correct form of deposit and layer.

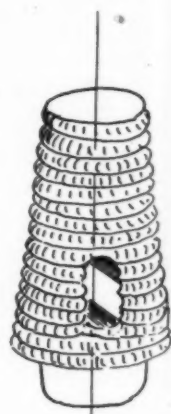


Fig. 7.—Hard facing a valve.

as shown in Fig. 5. Such technique is necessary when applying hard-facing to the valve shown in Fig. 7, for which a small rotating jig was made and a direct current arc-welding plant used. After welding on the hard-facing material the valve was machined to limits.

The high manganese steels are invariably hard-faced by means of the metallic arc, as, for example, steam-shovel bucket teeth, crusher jaws, etc. It should be remembered that the coefficient of expansion of this material is about 50% greater than a hard-facing alloy of the cobalt-chromium-tungsten type; another important fact is that when heated to welding temperature and subsequently cooled this steel is brittle, but its ductility can be restored by quenching the part affected from about 900° C.

The photographs in the article are reproduced by courtesy of the Deloro Smelting and Refining Co., Ltd.

### Personal

Major W. R. Brown, D.S.O., has been appointed a director of the Power-Gas Corporation, Ltd., and Mr. W. R. Beswick (London Manager), Mr. R. W. Rutherford (Technical Sales Manager), and Mr. Charles Robson (Secretary) have been appointed directors of Ashmore, Benson, Pease and Co., Ltd.

Lieut.-Col. Sir John Greenly, K.C.M.G., has accepted an invitation to become an honorary vice-president of the Iron and Steel Institute. Sir John Greenly was until recently President of the Institute of Metals.

### The Maudslay Society

THE Committee of the Maudslay Society inform us that they have decided to postpone the exhibition of Maudslay relics, which was announced to be held at the Institution of Mechanical Engineers on Saturday, May 6, but that the second annual general meeting of the Society will be held there on that date, as previously arranged, but at 11-30 a.m.

## Correspondence

### The Future of the Aluminium Industry

The Editor, METALLURGIA.

Dear Sir,

My attention has been drawn to the editorial under the above heading, in your March issue, upon which there seems to be only two matters calling for special comment: the implication that the industry is at fault in not saying what its prices are going to be after the war, and that the industry's general policy is uncertain.

Dealing with the latter point first, I find it difficult to understand why there should be any doubt that the industry's policy will continue to be expansionist, as it has always been in the past. There are some confused thinkers who feel that a policy of reasonable price stability is, of necessity, restrictive. On the other hand, and turning to hard facts, it could hardly be denied that an expansion in world aluminium production from five thousand tons in 1900 to six hundred thousand tons in 1938 indicates a desire for expansion, and the ability to achieve it, on the part of those connected with the industry.

Turning to the question of price policy, there is no doubt that the reasonable expansion in capacity which has taken place during the war must bring about substantial reductions in price, on the basis of pre-war values.

I fail, however, to understand why this industry should be singled out as being able to make an exact pronouncement as to what post-war prices will be. We can have no more idea than anyone else as to relative money values and as to the cost of many items outside our control, particularly transport, which have contributed so largely to our increased costs in war-time.

It is natural that potential users should desire information, and is indicative of the great interest which will focus on the metal during the post-war years. Anyone attempting, however, to state now what the price of aluminium will be in the post-war period would simply be making a guess. I find it difficult to imagine anything calculated to do more harm to the industry than to make such a guess in the full knowledge that it might have little relationship to ultimate reality.—Yours sincerely,

GEOFFREY CUNLIFFE,  
The British Aluminium Co., Ltd.

Salisbury House,  
London Wall, E.C. 2,  
March 28, 1944.

The Editor, METALLURGIA.

Dear Sir,

Thanks for the opportunity of seeing Mr. Cunliffe's comments on my notes on the above subject.

Although I was concerned more with post-war prices of aluminium alloy semi-finished products than with the prices likely to be quoted within the industry for virgin aluminium ingots, the comments under reference are certainly of interest. It is instructive, for example, to be assured that so far from having no post-war policy, as seemed probable from the lack of published advices, the British Aluminium Company has, in fact, a fixed policy and is determined to wait until a considerable measure of stability is reached some time after the war, before declaring what the price of virgin aluminium is likely to be.

Unfortunately for our industry as a whole, but equally unfortunately for the British aluminium industry, other industrial leaders are formulating plans now for their activities in the immediate post-war period. Undoubtedly, their schemes will be subject to some adjustment and modification, but at least their attitude is more realistic than that of an industry simply declaring that its policy is "expansionist."

The Americans have recently reduced their price for virgin aluminium ingot by 25%, which can be assumed from Mr. Cunliffe's comments as being, at least, foolhardy. On the other hand, however, it may be indicative of a desire to further the use of a metal, the continued consumption of which, after military aircraft production is virtually at an end, is vital to the welfare of several thousand employees.—Yours sincerely,

YOUR CONTRIBUTOR.

London, W. 1,  
April 4, 1944.

### Graded Fluorspar

The Editor, METALLURGIA.

Dear Sir,

As a consulting mining engineer called upon to direct the development and mining of a very large fluorspar deposit in County Durham, I was perplexed by the chaotic conditions prevailing generally in the production of this vital commodity, and, in contrast with the highly organised base-metal industry, the haphazard marketing of the product.

As a start, I endeavoured to ascertain with some degree of accuracy the chemical grade and size of fluorite most acceptable to the steel industry, but soon found a surprising divergence of opinion regarding even the principal adulterant of naturally occurring crude fluorspar—namely, silica. I found that the silica content of fluorspar as supplied to the steel companies ranged from 8% to as high as 20%, and that while some firms regarded silica as highly deleterious others considered the harmful effects were greatly exaggerated.

I am authoritatively informed that in the United States very close attention has been progressively paid by the steel industry to this question, and that the whole trend is towards the use of beneficiated fluorspar containing the lowest possible  $\text{SiO}_2$ . Various flotation treatments used necessitates, however, grinding of the crude spar to 120–200 mesh, and in order to avoid flue losses, the finely powdered concentrate is admixed with bonding media and briquetted.

In Britain similar flotation treatment is employed in order to reduce the silica content, but the powdered concentrate is used only in the hydrofluoric acid and ceramic industries, while a certain amount is used in electrolytic smelting of alloys, etc. The so-called "metallurgical grade," as sold to open-hearth steel producers, consists entirely of crude or jigged fluorspar, and, as stated, the silica and other chemical content of this material naturally varies greatly. There appears to be no "standard grade" so far as the steel industry is concerned, although the acid and ceramic firms insist upon a close approximation to their high-grade specifications.

With full knowledge of the circumstances resulting from the enormously increased demand for and the acute shortage of fluorspar, I fully appreciate that the steel companies have been compelled to accept adulterated fluorspar simply because they had no alternative. But I ask if this state of affairs will continue indefinitely?

Believing that it will not, I devoted my attention to the perfecting of processes whereby it is now practicable to produce fluorite (of almost any mesh) warranted to contain only a stated amount of silica, even as low as 2%, free from barium, lead, zinc, etc.; and a company is now being formed to operate these processes.

This guaranteed fluorite is of course eminently suitable for electrolytic smelting and ceramic work. The questions I wish to have answered are whether or not the British open-hearth steel producers are likewise interested in the reduction of silica in their supplies? To what extent? The cost of crude fluor per ton of steel produced is to-day well under 6d. What are they prepared to pay in order to obtain supplies of a chemically warranted grade? I have formed the personal opinion that no steel company should buy highly siliceous and often very impure crude fluorspar if it could obtain a guaranteed grade most suitable to its ideal requirements, but would like to know whether or not my view is confirmed by the steel firms themselves?—Yours faithfully,

J. NORMAN WYNNE,

F.G.S., M.Inst.M.M., M.Can.Inst.M.M.,  
M.Chem.M.M. Soc. (S.A.).

Plas Wynne,

Glyn Ceiriog, Nr. Wrexham,  
North Wales.

April 7, 1944.

### Furnace Control Operated from Load Temperature

The Editor, METALLURGIA.

Dear Sir,

I wish to draw your attention to a mis-statement of fact in the article under the above heading by Mr. Pamely-Evans, in your February issue. On page 173 he sets out to prove that "the heat loss in flue gases can be reduced by nearly 10% by changing from coal gas to blast-furnace gas . . . a drop of 9.3% in annual fuel bill."

This statement is fallacious, as it is based on equal flue gas volumes and entirely ignores the relative values of the heat released in combustion per unit volume of flue gases formed.

Unfortunately, the figures and units employed in the article are not clear, and it is not possible to follow the working. The accompanying schedule illustrates the point. It so happens that the particular coal gas analysis taken from "Technical Data on Fuel" does not show the increase of thermal capacity of flue gases claimed by the author, but this does not affect the main argument. It is, of course, true that for fuels of equal gross calorific value, that lower in hydrogen content will give lower flue-gas losses.

I would also point out that the statement on the same page that "only when the load reaches practically the same temperature as the furnace, and black body conditions obtain, can 100% emissivities be counted upon, and this is the time when such are least required, since the required rate of heat transfer is a minimum," is misleading, since, to prevent local overheating and possible overshoot, the temperature of the radiants must be reduced as near as possible to the required load temperature, this accentuation of reduction of temperature difference reduces still further the total rate of transfer over the latter part of the heating cycle, and any compensating increase of transfer per unit

Item.	Composition of Fuel by Volume.		Composition of Products by Volume.		Mean Specific Heat 32° to 1650° F.	Sensible Heat above 32° F.	Sensible Heat above 32° F.	
Units.	%		%		B.Th.U./cub. ft. per °F.	B.Th.U./cub. ft. at 1650° F.	B.Th.U./cub. ft. of Products at 1650° F.	
	B.F.G.	Coal G.	B.F.G.	Coal G.			B.F.G.	Coal G.
O <sub>2</sub>	—	0.4	—	—	—	—	—	—
CO <sub>2</sub>	11	2	24.6	8.7	0.0326	52.7	12.97	4.6
CO	27	8	—	—	—	—	—	—
H <sub>2</sub>	2	32	—	—	—	—	—	—
"CH <sub>4</sub> "	—	30	—	—	—	—	—	—
H <sub>2</sub> O	—	—	1.3	21.5	0.0252	40.7	0.53	8.8
N <sub>2</sub>	60	4	74.1	69.5	0.0206	33.4	24.75	23.3
Total	—	—	—	—	—	—	38.25	36.7

NCV per cub. ft. dry at 32° F.	B.F.G.	Coal G.
Cub. ft. produced per cub. ft. gas.	1.545	3.617
Available heat B.Th.U. per cub. ft. products.	63.5	94
Flue Gas Loss (from above) B.Th.U. per cub. ft. produced.	38.25	36.7
Percentage Flue Loss, %	60.25	39
Percentage Total Heat Utilised.	39.75	61

NOTE.—Thermal capacity can be found by dividing Total Sensible Heat by Temperature rise, B.F.G. 2.57, C.G. 2.27.

All data taken from "Technical Data on Fuel."  
All volumes measured at 32° F. and 29.92" Hg.

temperature difference will make a great difference to the total time to reach temperature.—Yours faithfully,

E. J. MARTIN, A.M.I.M.E., M.Inst.F.

Templewood Engineering Co., Ltd.,  
Slough.

March 27, 1944.

The Editor, METALLURGIA.

Dear Sir,

I am indebted to Mr. Martin for his criticism of my article on the above subject. In general, I am in agreement with his remarks regarding thermal capacities of flue gases, and fully appreciate his point that volume rate as well as thermal capacities enter into factor "A" in the expression—

$$\frac{dQ}{dB} = AT + [BT^4 - f(t^4)]$$

Also, the higher flame temperature of coal gas, as indicated in Mr. Martin's figures of 63.5 B.Th.U. per cub. ft. flue gas for B.F.G., and 94 B.Th.U. per cub. ft. flue gas for coal gas (70.6 and 94.1 respectively in the case of gases of analysis as given in my calculations) leads to a better performance of that gas. May I express my thanks to Mr. Martin for drawing attention to my error.

With regard to Mr. Martin's second point, I would point out that as black-body conditions are approached, the emissivities of the surfaces in the furnace tend to unity. There is, therefore, an increased rate of heat transfer per unit temperature difference between the radiating surfaces and the load. This is unfortunate, for it is at precisely this stage in the heat-treatment that the importance of close control is most apparent. Hence, the best condition would be one in which the rate of heat transfer per unit temperature differential was a minimum, allowing maximum movement to the control gear adjusting the temperature of the radiating surface.—Yours truly,

O. G. PAMELY-EVANS,  
B.Sc., A.R.I.C., Assoc. Inst. Gas E.

Cardiff, Glam.,  
April 6, 1944.

(Continued on page 325)



# Further Examples on the Damping Capacity of Metals

By the late W. H. Hatfield, D.Met., F.R.S., L. Rotherham, M.Sc., F.Inst.P.,  
and Miss E. M. A. Harvey, M.A., B.Sc.

(Of Brown-Firth Research Laboratories).

*The main objects of the work described concern the investigation of points raised in connection with a previous paper.*

**S**INCE the publication of the last paper on the damping capacity of metals from the Brown-Firth Research Laboratories, presented before the North-East Coast Institution of Engineers and Shipbuilders in May, 1942, it was the intention of the authors to review very carefully all the points arising from the discussion, and to conduct experiments where possible to meet the difficulties encountered earlier, and to fill any gaps in knowledge which had become apparent.

In introducing the results of experiments since carried out, and described at considerable length in a further paper before the same Institution in March this year, the authors refer to the most unfortunate check to the work proposed by the death of Mr. Stanfield. The loss of an experienced and distinguished engineer of the quality of Mr. Stanfield at an early stage in the investigations, serves to accentuate the loss suffered more recently in the death of Dr. Hatfield himself.

The authors of the present paper state that it will be obvious to all who were acquainted with Dr. Hatfield that by his death, coming as it did with overwhelming suddenness, one of the most forceful and brilliant metallurgists of his generation has been lost, and this paper must suffer from the loss of his guidance at a critical time. The work on damping capacity received in a very full way the personal direction of Dr. Hatfield and, since the writers of the present paper had the benefit of day-to-day contact with him, they were able to form a reliable picture of the way in which he intended the work to be carried out. They have attempted to complete the work on the lines laid down by Dr. Hatfield, and to prepare the data given in this report.

## Points Arising from Previous Discussion

As already mentioned, one of the main objects of the present work has been to investigate as many as possible of the points arising from the discussion of the previous paper. The most interesting of these lend themselves to arrangement in a series of groups, according to the aspect of damping capacity to which they are most closely related. These groups are summarised, and some indication is given as to the experiments which bear on them.

The first group embraces the factors which influence damping capacity. Some features of interest in this category which have been investigated in the present series of experiments are the effect of the number of impulses applied, and the effect of small temperature

changes such as would be encountered in the normal fluctuations of room temperature. Also in this group come the influence of external conditions, such as the surface finish of the test-piece, and the nature of the gas in which the apparatus is enclosed. Further, an attempt has been made to correlate damping capacity and magnetostriction, with very interesting results.

All the points of the second group deal with variations in the test conditions. Here, no experimental work has been carried out in attempts to answer these questions, since it was felt that it would at present be more valuable to continue with the apparatus in its original form. Some adjustment in the initial stress is possible with this apparatus, but not to the extent which had been suggested in the discussion. For similar reasons, the adoption of a mean stress other than zero was not practicable.

The third category deals with long-time testing. Here, a number of different experiments have been carried out, all of which deal with this aspect of the subject. An estimate of the effect of a long period of service on the damping capacity of a material was obtained from samples of a fan shaft which had been in service for some 30-40 years at the Clara Vale Colliery, and which was supplied by the courtesy of Messrs. C. A. Parsons and Co., Ltd. Also, continuous tests, extending up to a week's duration, have been carried out on three steels.

In the fourth category come the explanation for the very marked difference between the two mild steels, Nos. 1 and 2 of the previous paper, and the confirmation of the considerable rise in the damping capacity of No. 1 between 20° C. and 40° C. In this group should be classed tests carried out to explain the wide variation in the results on the stainless irons and stainless steels reported in the earlier paper, and tests on a carbon steel which had been subjected to various amounts of cold work.

Further experiments, not bearing directly on any of the points which were raised in the discussion, but which showed promise of interesting results, have been carried out. Among these may be mentioned the tests on casts in which the percentage of one element present was gradually varied, while keeping the composition of the base as constant as possible; this has been done for a series of carbon, chromium and nickel steels. Miscellaneous samples have also been received through the courtesy of makers of "Meehanite," "Stellite," and G.E.C. Heavy Alloy, and the values of damping capacity of these materials are given.

### Forms of Expression of Damping Properties

The various methods which have been employed for expressing the damping characteristics of materials are reviewed. Zener† summarised some of the different measures of internal friction. From the observations of the decay of free vibrations the logarithmic decrement  $\delta$ , and the energy ( $\Delta E$ ) lost per cycle can be calculated. This  $\Delta E$  divided by the maximum energy ( $E$ ) of the cycle gives the "Specific Damping Capacity" used by Föppl. Another method is to take a vibrating sample to which a given amount of energy is supplied, at a frequency near the resonance frequency and observe the amplitude of the vibration at which the sample settles down. This varies with the frequency so that a "resonance curve" can be plotted. The range of frequencies  $\Delta v$  on this curve for which the amplitude of vibration exceeds half the maximum amplitude corresponding to the frequency  $v$  at resonance, expressed as a fraction of this frequency  $v$  has been used as a measure of the damping.

In one form of test the vibrating solid is part of the mechanism of an electric circuit with an oscillating current. The effect of the energy losses can be expressed in terms of the effect on the impedance of the circuit and a quantity  $Q$  is arrived at in these terms and  $1/Q$  is employed by Zener as a measure of internal friction.

Finally, Kimball and Lovell‡ have defined an internal friction constant  $\xi$  given by  $F = \xi F^2 M$  in their notation, where  $F$  is the frictional loss and  $F M$  the amplitude of the stress cycle.

These various measures of the damping property of the material are connected as follows:—

$$\text{Damping Capacity } \frac{\Delta E}{E} = 2\pi \frac{1}{Q} = \frac{2\pi}{\sqrt{3}} \cdot \frac{\Delta v}{v} = 2\delta = q\xi$$

where  $q$  is Young's Modulus, and the other symbols have the meaning given above.

The different measures of damping have been adopted to suit the different methods of measurement. In the present paper the simplest method of computing the damping was to take the ratio  $\Delta E/E$  and this is the value recorded.

### Apparatus Used in the Present Work

The apparatus used in the present work is similar to that described in the earlier paper, the only difference being in the camera; for this reason, only the camera will be described here.

This camera is unique, and was designed and built in the Laboratory. It is a constant-speed continuous-film recording camera, the film being driven by friction through electrically driven rubber rollers. It is equipped with day-light loading cassettes, and permits the use of film varying in width up to 120 mm.; the width of the slit is also variable. A two-speed gearbox is fitted so that the rate of movement of the film may be adjusted to suit the frequency of the vibration under observation. This feature gives a camera which has a wide range of usefulness, and the authors express their indebtedness to Mr. S. H. Thorpe of these Laboratories for the design and construction of the instrument.

All values of damping capacity recorded are mean values from two tests only. Between these two tests, the

specimen was removed from the machine and rotated through 90°.

### Materials Used

The authors have collected together, in three tables, details of all the materials used in the tests, including composition, heat-treatment, mechanical properties, and a single value of damping capacity so that easy comparison of these materials with those recorded in the earlier paper is possible.

### Experimental Tests

A large number of tests are described in sections, each designed to determine the effect of a particular factor on the value of damping capacity recorded. These factors include air resistance, long period of service, small temperature changes, the degree of reproducibility from the same bar, the degree of reproducibility from different casts of the same material, variation of carbon content, variation of chromium content, variation of nickel content; a further section deals with miscellaneous tests, most of which bear little relationship to one another, while sections deal with tests to determine the influence of defects and added sulphur, of cold work, and of surface finish; the last section dealing with tests on miscellaneous materials, including Meehanite, Stellite, and G.E.C. Heavy Alloy.

The results of tests are discussed and consideration is given to probable sources of error in damping capacity determinations. The chief points considered were:—

- (a) The inherent error in the machine and in the measuring device used.
- (b) The error which might be obtained, due to inserting the test-piece in the machine in any of eight different possible positions.
- (c) The degree of reproducibility of results from a given record when calculated by two different operators.
- (d) The reproducibility of results from different test-pieces from the same bar of material.

The methods of calculation used, the authors state, were in accordance with standard practice, using the "standard deviation," and no actual calculations are, therefore, given.

### Conclusions

From the various tests described, most of which had been designed to examine some particular aspect of damping capacity, and the results obtained from them, which are shown graphically in Figs. 1 to 5, the authors formed the following conclusions:—

Experiments carried out in vacuo and in a 3:1 hydrogen/air mixture indicated that any contributions of air-damping to the values of damping capacity recorded may be neglected.

The effects of long period of service, and of continuous testing up to a period of a week, have been investigated, no effect outside the limits of experimental error have been detected.

The degree of reproducibility of results from a number of samples from the same bar of 0.12% carbon steel has been found to be very good, while that between different casts of the same material has been found to be not so marked; nevertheless, the results were, in each case, characteristic of the material. Small variations in temperature, of the type encountered in the normal fluctuations of room temperature have been found to be very important, with 0.12% carbon steel, quite marked

† *Phys. Soc.*, vol. 52, p. 152.

‡ *Phys. Rev.*, 30, pp. 948-959, Dec. 1927.

with 18/8 stainless steel, and unimportant with stainless iron and stainless steel (0.20% C, 13.26% Cr).

Fairly good correlation has been obtained when damping capacity is plotted against the carbon content of carbon steels, the degree of correlation being highest when the samples are obtained from approximately the same size of bar, and are in the same heat-treated condition.

Interesting results were obtained from the series of chromium steels tested. The first four steels of the series (2.16%, 5.39%, 8.50%, and 11.44% chromium) all of which exhibited the same type of microstructure, showed an increase of damping capacity with increasing chromium content up to 8.5% chromium, the values for the 8.5% and 11.44% chromium steels being identical within the limits of error of the experiment. The high values for these last two steels indicate that

Fig. 2.—Damping capacity of 0.12% and 1.32% carbon steels.

(C 0.12, Si 0.24, Mn 0.52, Ni 0.16, Cr 0.18)  
Normalised at 900° C.  
(C 1.32, Si 0.15, Mn 0.24, Ni 0.26, Cr 0.16)  
Normalised at 975° C.

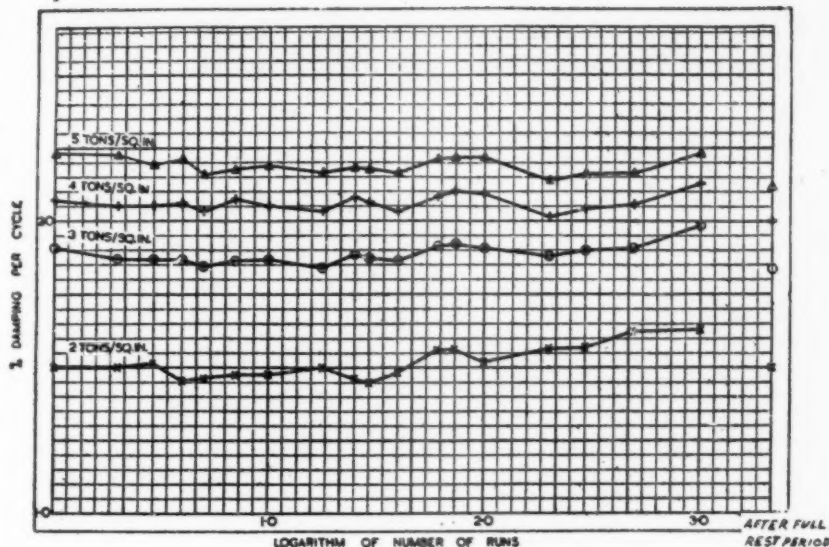
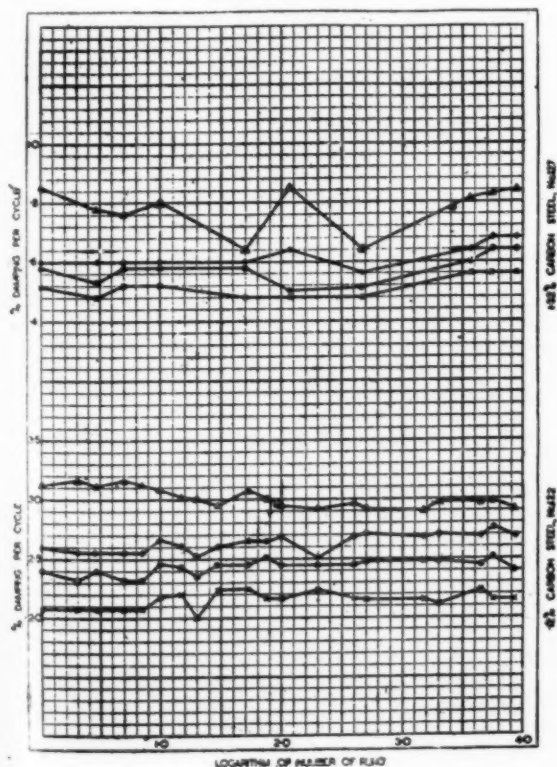
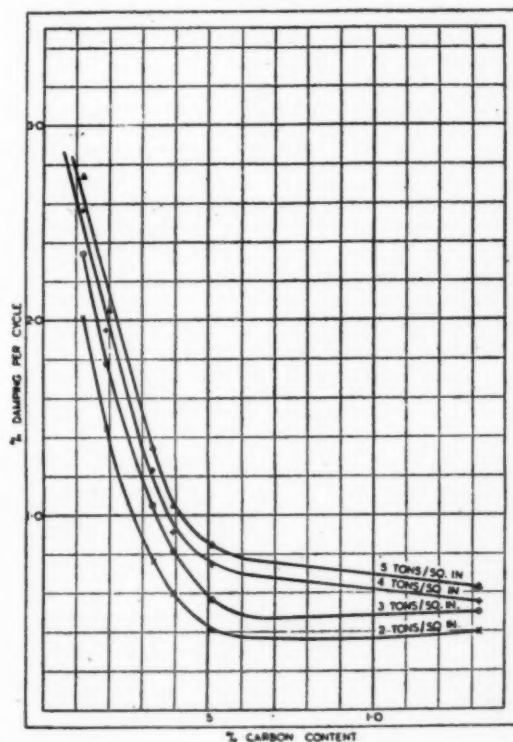


Fig. 1.—Damping capacity of 0.12% carbon steel.

(C 0.12, Si 0.27, Mn 0.56, Ni 0.14, Cr 0.06.)  
Normalised at 900° C.

the values recorded for the stainless irons and stainless steels are not anomalous, but are dependent on the composition of the material, or on some other factor which itself varies with the composition. The relatively low values of the high chromium stainless iron and of the

Fig. 3.—Results showing that increasing carbon content caused a rapid decrease in damping capacity.





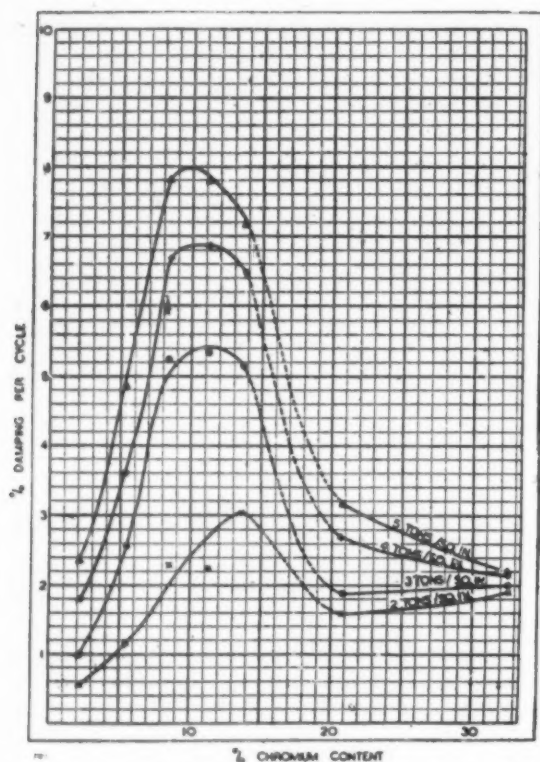


Fig. 4.—Damping capacity values from tests of six steels, in which the chromium content varied from 2.17% to 33.19%.

21% and 33% chromium steels gave further evidence of the shape of the curve plotted between damping capacity and chromium content.

A successful attempt was made to correlate damping capacity with magnetostriction for the series of iron-

nickel alloys. The curves given in Fig. 7 show that, when the sign of the numerical coefficient of magnetostriction is neglected, the shape of the magnetostriction curve is followed closely by the damping capacity curves.

The influence of defects on the damping capacity of materials has been noted. In both the cases studied, the cracked specimens gave higher values of damping capacity than those without cracks. The greater difference observed with the specimens of 3½% nickel chromium steel was probably due to the greater number of defects present. Magnetic-etching of the defective specimens from both the 3½% nickel-chromium steel bar and the 3¼% nickel steel forging had indicated that a larger number of defects were present in the former than in the latter.

The addition of extra sulphur to an ingot of 3½% nickel-chromium-molybdenum steel caused an increase in damping capacity. Similar additions of sulphur to corrosion-resisting materials caused little change in the values of damping capacity recorded.

The few experiments carried out on 0.13% carbon steel to assess the effects of cold-work show that, with this material, the result of cold-work is to decrease the damping capacity. This is in line with the results on the corrosion-resisting materials from the earlier paper. After re-tempering in the laboratory, the values of damping capacity of all these materials were increased.

Tests on a 0.33% carbon steel specimen with three different finishes indicated that variations in surface finish of this type do not affect the values of damping capacity recorded.

Of the miscellaneous materials tested, the Mechanites gave further estimates of the degree of reproducibility obtainable both between casts and within a cast. The values of damping capacity recorded for this material, which is a type of cast-iron, were lower at all stresses than the corresponding values for the other cast-irons reported in the earlier paper. The other miscellaneous materials, the Stellites and G.E.C. Heavy Alloy, may perhaps be classed with the sintered carbides and the 99.25% cobalt on which tests had previously been carried out.

The results are also noted of a quantitative investigation of the degree of reproducibility of results in different test conditions, together with an estimate of the reliability of the procedure adopted.

### Bessemer Gold Medal for 1944.

The Council of the Iron and Steel Institute have awarded the Bessemer Gold Medal for 1944 to Mr. Essington Lewis, C.H., Director-General of Munitions and Director-General of Aircraft Production for Australia, formerly of the Broken Hill Proprietary Co., Ltd., in recognition of his outstanding services to the iron and steel industry of Australia.

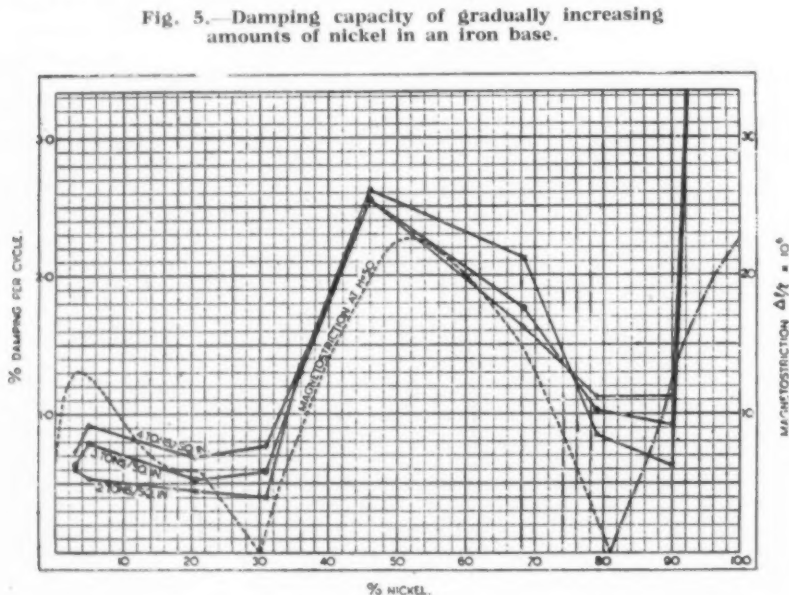


Fig. 5.—Damping capacity of gradually increasing amounts of nickel in an iron base.

# Gold and Silver Winning by Amalgamation

By Douglas Rennie Hudson, B.Sc., Ph.D.

(Lecturer in Metallurgy, Heriot-Watt College, Edinburgh).

## Part II.—Theoretical

παρὰ τούτοις δε λέγεται καὶ χρυσὸν καταφέρειν τοὺς χειμάρρους, ὑποδεχέσθαι δ' αὐτὸν τοὺς βαρβάρους φάρναις κατατετρημέναις καὶ μαλλωταῖς δораῖς· ἂψ' οὐ δὴ μεμνηεῖσθαι καὶ τὸ χρυσόμαλλον δέρος·

It is said that amongst them [Caucasians] gold is carried down by the mountain streams, and that the barbarians obtain it by means of perforated troughs and fleecy skins, and that this is the origin of the myth of the golden fleece.

STRABO (Geography, 11 (2), 19.

### ABSTRACT.

Some previous explanations of the amalgamation process of gold winning are shown to be ill-founded theoretically. Quantitative determination shows that a mercury layer about  $2.2 \times 10^{-4}$  cm. in thickness is enough to impart the typical greasiness and high reflecting power to gold.

From a review of the mechanism of amalgamation and the constitution diagrams of gold- and silver-amalgam, the following explanation is proposed:—In water the native metals in the pulp sink under gravity on account of their high densities, 19.3 and 10.5, compared with 2.65 for the quartz gangue. On touching the liquid mercury they are held like flies on a fly-paper on account of its high surface tension, intermetallic combination plays no part in this. Evaluation of the ratio  $R = (\text{force for dislodgement}/\text{force of gravity}) = \text{Py}/\text{Mg}$  for five different shapes idealised from dendrites, filiforms, and the assayer's *metallics*, shows that it is little affected by the *shape* of the particle, but is very sensitive to *size*, increasing inversely as  $l^2$ . The amalgam finally consists of native metal particles immersed in liquid mercury; the intermetallic compounds  $\text{Ag}_2\text{Hg}_3$  and  $\text{AuHg}_2$  are slowly formed by diffusion, and may be predominant where the metal grains are fine or where contact is prolonged.

### 1.—PREVIOUS EXPLANATIONS.

NOTWITHSTANDING the immense importance of the gold amalgamation process—technical, economic, sociological—theoretical investigation has been scanty, and many explanations are highly confused. Schnabel, *Handbook of Metallurgy*, New York, 1905, stated that an amalgam with 10% gold was fluid. Actually it will contain 30% of Solid  $\text{AuHg}_2$  (according to Plaksin's diagram)<sup>1</sup> if equilibrium is reached, although this is not necessarily the case in mining amalgamation. Mellor<sup>2</sup> (1923) stated: "The gold is miscible with mercury in all proportions, and small particles of the liquid amalgam in the sluices coalesce into larger globules which collect in the inequalities at the bottom." This in spite of the prior observation by Kasanev<sup>3</sup> in 1878, that the gold content of mercury expressed from the amalgam was only 0.11, 0.126, and 0.65% at 0°, 20°, and 100° C. respectively. On the other hand, Rose, in 1912, had reported correctly,<sup>4</sup> "Gold will absorb about six times its weight of mercury, forming a silver-white solid amalgam containing about 13.5% of gold but in ore treatment time does not admit of the complete saturation of the gold with mercury, which slowly penetrates into the solid metal by diffusion. The result is that the gold amalgam collected in the cleaning up in a gold mill consists of little 'nuggets' of gold immersed in a bath of mercury by which their outer layers are saturated. . . . If the gold is finely divided, the penetration by mercury is more nearly complete than if the particles of gold are comparatively large. Generally speaking, squeezed amalgam resulting from the treatment of gold ores contains from 20 to 50% of gold."

One may recall Pliny's account that on squeezing the solid amalgam in a leather bag, the quicksilver exudes like a sweat, *per quas sudoris vice defluit*, leaving the pure gold. This is repeated by Agricola: "*Lavatur priusquam cum argento vivo permisceatur . . . quae delapsa argentum vivum in se trahit atque purgat . . . comprimitur, argentum vivum per eam defluit in ollam subiectam: aurum in ea remanet purum.*"

Many critics and translators have commented adversely on the "error," but the author does not feel convinced. The industrious Pliny had no first-hand knowledge of many of the processes he described—he was as careful to cite authorities as the writer of a scientific memoir to-day; his credulity, though patent, nowhere approached that of Aristotle and the peripatetic school. Agricola, however, was not only very careful, but a pioneer of personal investigation, and his description probably comes from observation. Whether or no the account was Pliny's own, the author believes that both are substantially accurate, and the explanation of the "pure gold" remaining behind is that only short contact times were used with much larger particles of gold than those common to-day.

### 2.—THICKNESS OF THE MERCURY FILM.

On amalgamation, the gold surface becomes white, highly reflecting like a liquid metal and greasy to touch, particles stick together on contact. Only a minute amount of mercury is necessary to effect this, a small drop will amalgamate a remarkably large area.

*Quantitative Measurement.*—Determination by direct weighing gave the following results for various metals and alloys amalgamated by rubbing. Amalgamation of large surfaces with long-continued rubbing might yield lower values—i.e., a greater spread might be accomplished—the figures are, therefore, to be regarded as

<sup>1</sup> Plaksin, *Ann. Inst. Anal. Phys. Chim.*, **10**, p. 129, 1938. In Russian.

<sup>2</sup> Mellor, *Comprehensive Text Book of Chemistry*, **3**, p. 497, London, 1923.

<sup>3</sup> Kasanev, *Bull. Soc. Chim.*, [2], **30**, p. 20.

<sup>4</sup> Rose, *Thorpe's Dictionary of Applied Chemistry*, London, 1912.

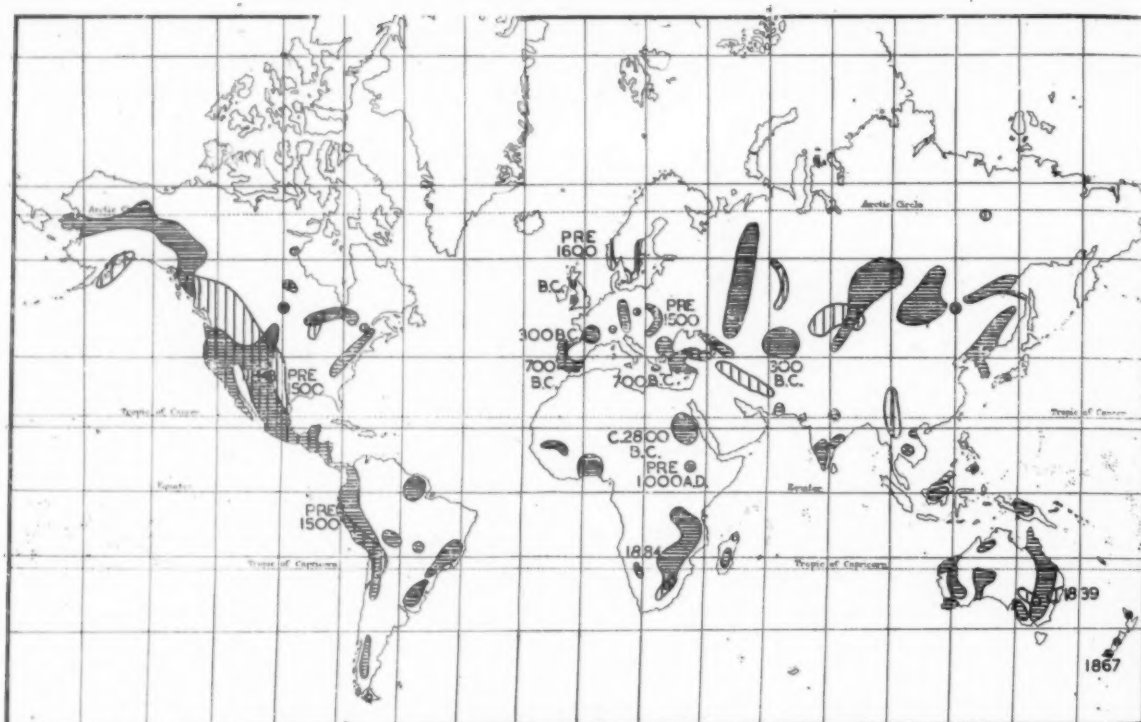


Fig. 1.—Showing distribution of auriferous and argentiferous minerals with dates of exploitation. Gold—horizontal shading. Silver—vertical shading.

upper limits; even so, the remarkable thinness of the film is evident.

TABLE I.

THICKNESS OF FILM ON VARIOUS METALS AND ALLOYS OBTAINED BY RUBBING WITH MERCURY AT ROOM TEMPERATURE.

Substance.	Mass of Hg/Cm <sup>2</sup> .	Thickness of Film.	Remarks.
Silver, fineness 999.54	3.7 mg.	$2.7 \times 10^{-4}$ cm.	Half-Hard-rolled
Gold, fine .....	3.0 mg.	$2.2 \times 10^{-4}$ cm.	—
Rolled Gold .....	0.3 mg.	$0.22 \times 10^{-4}$ cm.	—
18-ct. Gold alloy ....	3.7 mg.	$2.7 \times 10^{-4}$ cm.	This was hard-rolled and cracked by season cracking in contact with mercury.

### 3.—WETTING OF METALS BY MERCURY.

*Mechanism of Amalgamation.*—Saïni has reviewed the thermodynamics of amalgamation.<sup>5</sup> The correct explanation of the process seems to be as follows:—Neither gold nor silver has any tenacious oxide film on its surface, the compounds are unstable at high temperatures. Further, both metals are wetted by liquid mercury. "Wetting" seems to be an interface phenomenon, and does not depend on solubility of the metal in the liquid, nor on the surface tension—e.g., platinum is wetted immediately by solder (or tin), but not by mercury—gold is wetted by both. The effect is therefore mutual and selective. A copper surface wets readily, but only after removal of the oxide film which electron diffraction shows to exist, friction or scouring is therefore required; reduction in heated hydrogen is not so effective. The author believes that wetting is purely physical, and not dependent on the formation of intermetallic compounds at the interface. In the

ultimate, however, solvation, intermetallic combination, and surface adhesion are all dependent on attraction between unlike atoms of the metal pairs concerned, whether *Coulomb* forces or *van der Waals* forces, or both, are concerned. A metal like gold or silver, therefore, which forms an intermetallic compound with mercury, recognisable as such, might be expected to be wetted more readily than one which does not. Plaksin and Koshuchova<sup>6</sup> have shown that even with gold, silver, and their alloys, wetting by mercury is promoted by mechanical polishing or electrolytic reduction; this is due to removal of the oxide or oxygen film existing at room temperature, although electron diffraction shows this to be hardly perceptible. To use an old-fashioned but still serviceable chemical concept, the affinity for oxygen increases in the order—gold, silver, copper. The above authors have reported further:—

1. The value of  $\cos \theta$  is greatest for gold, and least for silver, during the first minute of contact.
2. After 60 mins. maximum values of  $\cos \theta$  were obtained with a 98% gold alloy and negative values with 10–55% Au alloys.
3. The effect of fouling the mercury by alloying small amounts of copper and zinc with it was, in general erratic. The retarding action was ascribed to oxide films at the amalgam surface and was diminished in acid solution.
4. Gold is more easily wetted than silver, and at 60–90% gold there is considerable reluctance to wet in silver-gold alloys.

The final point is of interest in view of the fact that natural gold usually contains some alloyed silver. The

<sup>5</sup> Saïni, *Arch. Sci. phys. nat.*, **10** [v] Suppl., p. 189, 1934.

<sup>6</sup> Plaksin and Koshuchova, *Ann. Sect. Platin.*, **13**, p. 95, 1936. In Russian.



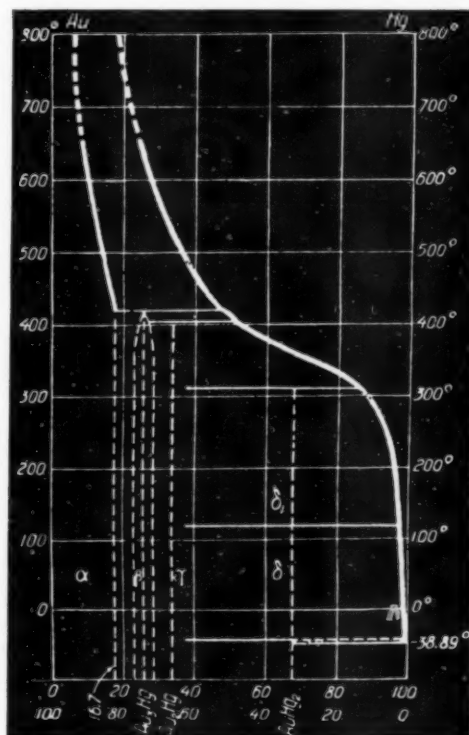
alloy, when pale yellow, has been identified with Egyptian *asem* and even with the biblical *chashmal*, rendered *ηλεκτρος*, *electrum*, and amber, in the Greek, Vulgate, and Authorised Versions.

#### 4.—THE GOLD-MERCURY CONSTITUTION DIAGRAM

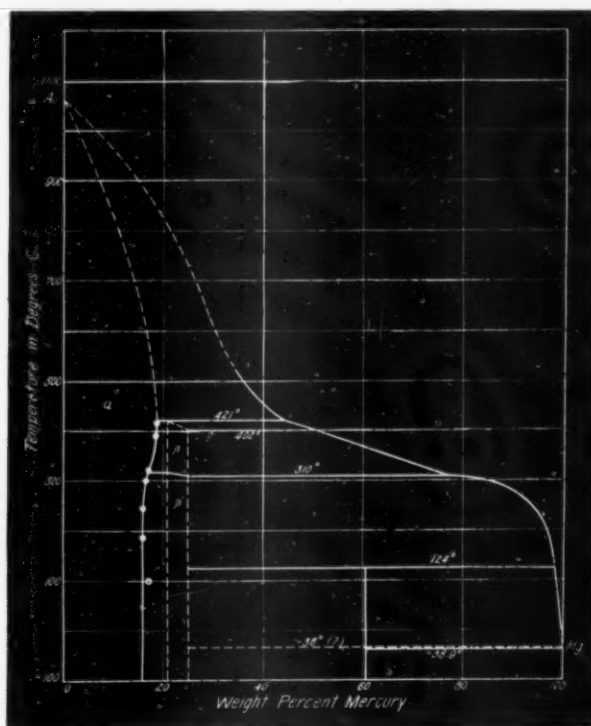
In 1921, Braley and Schneider<sup>7</sup> suggested that three intermetallic species existed,  $Au_3Hg$  and  $Au_5Hg_3$  melting at  $490^\circ$  and about  $290^\circ$  respectively, and  $AuHg_2$  formed

gold-rich phase  $Au_3Hg$  ( $\beta$ ) has a range of composition of about 6%, that of the others is probably small. The solid solubility of mercury in the gold lattice is about 17%, and varies little with temperature, in good agreement with the X-radiological results of Day and Mathewson (Fig. 2B).<sup>9</sup>

Whatever modification may be made to this diagram as a result of subsequent work, it is clear that its similarity to that for silver amalgams is very close.



A—Plaksin (1938).



B—Day and Mathewson (1938).

Fig. 2.—Gold-mercury constitution diagram.

by peritectic reaction at  $110^\circ$  C. Britton and McBain, at Bristol,<sup>8</sup> in an investigation of the mercury-rich amalgams, found a flat maximum at  $342^\circ$  C. and 146% gold, corresponding to  $342^\circ$  C. This result was obtained by direct solubility determination, but using methods similar in principle, several American investigators have failed to reproduce it. Parravano's electrical resistance method is probably not so accurate, although theoretically sound.

**Recent Work.**—Plaksin has recently (1938) published the results of a very complete investigation at Leningrad, using thermal, X-radiological, and microscopical technique. He finds good evidence for the following peritectics (Fig. 2A):—

1. At  $420^\circ$  C.  $Au_3Hg \rightleftharpoons 3Au + Hg$
2. At  $402^\circ$  C.  $Au_5Hg_3 \rightleftharpoons Au_3Hg + Hg$
3. At  $310^\circ$  C.  $AuHg_2 \rightleftharpoons Au_3Hg + Hg$

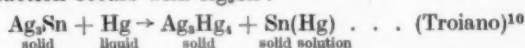
Further,  $AuHg_2$  undergoes polymorphic transformation at  $122^\circ$ , and a change at  $-36^\circ$  is very close to the melting point of pure mercury. The

Metastability in silver amalgams is proverbial, as all investigators have emphasised, and silver resembles gold very closely in physical properties, atomic structure and dimensions; a similar reluctance to reach equilibrium in the gold-mercury system would therefore cause no surprise.

#### 5.—REACTIONS IN THE AMALGAMS.

If equilibrium were attained in amalgamation mining, the succession of phases would be that cut by the isotherm on the diagram. In actual experience the result is very different. With silver and mercury two quite opposite results can be obtained, according to the conditions imposed:—

1. When fine silver filings are triturated with mercury, conversion to the mercury-rich phase  $Ag_3Hg_4$  is complete in less than a minute. In dentistry, a very similar reaction occurs with  $Ag_3Sn$ :—



<sup>8</sup> Britton and McBain, *J. Amer. Chem. Soc.*, **48**, p. 593, 1926.

<sup>9</sup> Day and Mathewson, *Amer. Inst. Min. Met. Eng. Tech. Publ.*, **364**, 1938.

<sup>7</sup> Braley and Schneider, *J. Amer. Chem. Soc.*, **43**, p. 740, 1921

2. When lump silver is immersed in mercury, the proportion of compound formed is so small that it can be neglected in determination of solubility; thus we may regard the solid silver-rich solution as in virtual equilibrium with the mercury-rich liquid solution; this holds up to 450° C. at least. That a *substrate of compound does exist* follows from De Right's demonstration that the same solubility of silver in liquid mercury is obtained by analysis, no matter whether silver or the compound  $\text{Ag}_2\text{Hg}_3$  is used as starting material. In the absence of friction, however, the thin film of compound rapidly chokes the reaction.

The other intermetallic compound  $\text{AgHg}$  (or  $\text{Ag}_3\text{Hg}_4$ ) containing about 40% silver, is not easily obtained by reaction between the metals.

In mining amalgamation, Case 1 corresponds to addition of quicksilver to the mortar box. Case 2 corresponds to addition of quicksilver to washery flumes, especially when the placer gold is coarse—gravel or nuggets. Table amalgamation lies somewhere between these extremes, with a bias towards 1 when the rock has been stamped fine, and there is much agitation of the pulp.

#### 6.—GOLD WASHING.

Separation of the native metals from a siliceous gangue depends chiefly, if not entirely, on the difference in the respective densities. The densities of gold and silver (19.3 and 10.5 respectively) are far greater than that of quartz (2.65) and when these substances are suspended in water, the ratio of "effective" densities will be  $(19.3 - 1)/(2.65 - 1) = 12$  approx. for gold; and  $(10.5 - 1)/(2.65 - 1) = 6$  approx. for silver.

Although settling of the particles under agitation will not be given *exactly* by Stokes' law—

$$\eta = d^2 \times k (\Delta_{\text{solid}} - \Delta_{\text{liquid}}) g/v$$

a similar relation might be expected to hold.

Since the viscosity  $\eta$  of the medium (water) is constant, the terminal velocities  $v$  of equal-sized particles of gangue and metal would then be proportional or approximately proportional to the "effective" densities.

Such a conclusion would be completely vitiated if there were any selective wetting of the metal particles, *vis-à-vis* the gangue, like that deliberately induced by addition of the complex soap in separation by flotation, but there is no reason to suppose that any such effect exists.

The ability of water to transport minerals is approximately proportional to the sixth power of its velocity.

#### 7.—RECOVERY OF THE AMALGAM CONSTITUENTS.

**Dissociation on Heating.**—The plastic amalgam is squeezed in wash-leather or canvas, leaving the native metal and the dendrites of intermetallic compound almost pure. As may be seen from the diagrams, both  $\text{AuHg}_2$  and  $\text{Ag}_3\text{Hg}_4$  undergo peritectic transformations, forming eventually a solid solution in equilibrium with a mercury-rich liquid solution. Since the (mercury) vapour pressure of the latter is high, the amalgams are easily split into a quicksilver distillate and precious metal residue (Fig. 2).

On rubbing gold with a little mercury, a dull lustre and white colour is first observed; with more mercury the surface becomes greasy and reflectivity increases.

When this is warmed the bright lustre again becomes dulled as though the liquid mercury were reacting with the gold. On further heating, the dulled surface becomes cream coloured, and eventually the yellow colour of gold is restored with the complete volatilisation of the mercury.

#### 8.—SUGGESTED MECHANISM OF THE AMALGAMATION PROCESS.

The function of the amalgamation process is somewhat as follows: The particle touches the liquid quicksilver and is wetted by it. The force exerted by surface tension is then so much greater than the weight of the particle that removal is very difficult. In action, therefore, *the amalgamation table resembles nothing so much as a gigantic fly-paper*, with gold particles for flies. Despite the fantastic explanations which have been published in the meantime, Pliny had come very near the truth in A.D. 77. "All substances float on the surface of quicksilver with the exception of gold, this being the only substance it attracts. This is why it is such an excellent refiner of gold; since, on being agitated briskly with gold in a clay pot, it rejects all the impurities that are mixed with it."

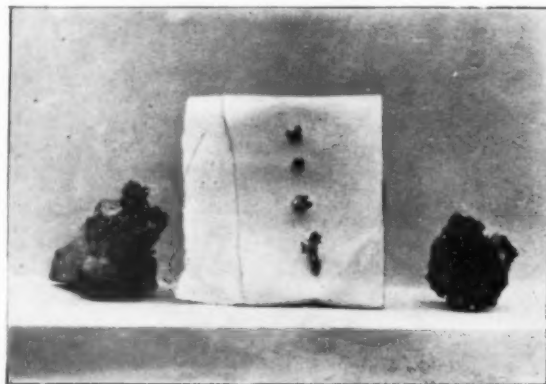


Fig. 3.—Native gold and silver, showing well-formed crystal development.

Centre—Dendritic native silver lent by Acting Prof. James Sandilands, Heriot-Watt College, Edinburgh.  
Flanks—Native gold from rich Rhodesian ore with quartz gangue, lent by Mr. Belsille, Keeper of Mineralogy, Royal Scottish Museum, Edinburgh.

#### Effect of Size and Shape

The ratio (force for dislodgement/gravity) obviously depends on (a) *size*, (b) *shape* of the gold particles.

(a) *Size*.—Despite careful search, the author has found only one set of data. Edman,<sup>11</sup> in a particle of auriferous quartz  $\frac{3}{16}$  in. in size, counted over 300 gold particles, varying from  $\frac{1}{1000}$  to  $\frac{1}{12500}$  in., under a  $\times 50$  magnification. Under higher power more particles were visible. As is clear from Table II, this ratio increases rapidly with decreasing size, but the amalgamation process does not necessarily become more efficient, since there is difficulty in bringing the finer particles into contact with the mercury.<sup>12</sup> This is well known in gold-mining.

(b) *Shape*.—As is well known, gold and silver crystallise in the close-packed cubic lattice, but the existence of well-formed natural crystals is a great rarity. Dendritic and arborescent forms predominate, especially in the larger growths (see Fig. 3). For calculation, we idealise

<sup>10</sup> Trolano, *J. Inst. Met.*, **63**, p. 217, 1938.

<sup>11</sup> Mellor, *Comprehensive Text Book of Chemistry*, **3**, p. 498, London, 1923.

TABLE II.

Ratio  $R = (\text{force to dislodge metal particle from amalgam/weight of particle})$  is calculated for the following shapes:—

1. *Rods of square cross-section*:  $b = h = l/10$ .

2. *St. George's Cross*, formed by two of the former intersecting at right-angles at their centres.

These shapes are an approximation to the fundamental dendritic structure: the value of  $R$  will not be much affected by altering the angle of intersection or by adding similar elements to the structure—i.e., "lengthening the chain."

3. *Rods of cylindrical cross-section*:  $d = l/10$ , simulating filiform metals.

4. *Circles*: thickness =  $d/100$ .

5. *Ellipses*: thickness =  $d/100$ , lesser axis =  $d/2$ .

4 and 5 correspond to the assayer's *metallics*, formed in stamping of the metal particles.

Shape.	Periphery P (Cm.)	Force $P\gamma$ (Dynes.)	Volume $v$ (Cm.) <sup>3</sup>	Mass $\Delta r$ (gm.).		Ratio $R = \frac{P\gamma}{Mg}$	
				Gold.	Silver.	Gold.	Silver.
1. Rectangular— $(2l + 2 \times .1l\sqrt{2})$			$0.01l^3$				
$l = 1$ cm.	2.28	1072	0.01	0.193	0.165	5.7	10.4
0.1 cm.	.228	107.2	.001	.0193	.0165	$5.7 \times 10^3$	$10.4 \times 10^3$
0.01 cm.	.0228	10.72	.0001	.00193	.00165	$5.7 \times 10^4$	$10.4 \times 10^4$
0.001 cm.	.00228	1.072	.00001	.000193	.000165	$5.7 \times 10^5$	$10.4 \times 10^5$
2. St. George's Cross (4l)			$(2 \times .01l^3 - .001l^3)$				
$l = 1$ cm.	4.0	1880	0.019	0.3667	0.1995	5.2	9.6
0.1 cm.	.4	188	$.019 \times 10^{-2}$	$.3667 \times 10^{-2}$	$.1995 \times 10^{-2}$	$5.2 \times 10^3$	$9.6 \times 10^3$
0.01 cm.	.04	18.8	$.019 \times 10^{-4}$	$.3667 \times 10^{-4}$	$.1995 \times 10^{-4}$	$5.2 \times 10^4$	$9.6 \times 10^4$
0.001 cm.	.004	1.88	$.019 \times 10^{-6}$	$.3667 \times 10^{-6}$	$.1995 \times 10^{-6}$	$5.2 \times 10^5$	$9.6 \times 10^5$
3. Cylindrical— $(2l + 2 \times .1l)$			$\pi l^3/400$				
$l = 1$ cm.	2.2	1034	0.007854	0.1516	0.0825	7.0	12.8
0.1 cm.	.22	103.4	$.007854 \times 10^{-2}$	$.1516 \times 10^{-2}$	$.0825 \times 10^{-2}$	$7.0 \times 10^3$	$12.8 \times 10^3$
0.01 cm.	.022	10.34	$.007854 \times 10^{-4}$	$.1516 \times 10^{-4}$	$.0825 \times 10^{-4}$	$7.0 \times 10^4$	$12.8 \times 10^4$
0.001 cm.	.0022	1.034	$.007854 \times 10^{-6}$	$.1516 \times 10^{-6}$	$.0825 \times 10^{-6}$	$7.0 \times 10^5$	$12.8 \times 10^5$
4. Circular— $\pi d$			$\pi d^3/400$				
$d = 1$ cm.	3.142	1477	0.007854	0.1516	0.0825	10.0	18.2
0.1 cm.	.3142	147.7	$.007854 \times 10^{-2}$	$.1516 \times 10^{-2}$	$.0825 \times 10^{-2}$	$10.0 \times 10^3$	$18.2 \times 10^3$
0.01 cm.	.03142	14.77	$.007854 \times 10^{-4}$	$.1516 \times 10^{-4}$	$.0825 \times 10^{-4}$	$10.0 \times 10^4$	$18.2 \times 10^4$
0.001 cm.	.003142	1.477	$.007854 \times 10^{-6}$	$.1516 \times 10^{-6}$	$.0825 \times 10^{-6}$	$10.0 \times 10^5$	$18.2 \times 10^5$
5. Elliptical— $\pi \left( \frac{3}{2} \left[ \frac{d}{2} + \frac{d}{4} \right] - \sqrt{\frac{3}{2} \frac{d}{2} \frac{d}{4}} \right)$			$\pi d^3/800$				
$d = 1$ cm.	2.356	1107	0.003927	0.0758	0.0412	11.0	27.4
0.1 cm.	.2356	110.7	$.003927 \times 10^{-2}$	$.0758 \times 10^{-2}$	$.0412 \times 10^{-2}$	$11.0 \times 10^3$	$27.4 \times 10^3$
0.01 cm.	.02356	11.07	$.003927 \times 10^{-4}$	$.0758 \times 10^{-4}$	$.0412 \times 10^{-4}$	$11.0 \times 10^4$	$27.4 \times 10^4$
0.001 cm.	.002356	1.107	$.003927 \times 10^{-6}$	$.0758 \times 10^{-6}$	$.0412 \times 10^{-6}$	$11.0 \times 10^5$	$27.4 \times 10^5$

these to a St. George's Cross. In stamping, the smaller particles will be pounded flat—the assayer's *metallics*—we assume these to be circles or ellipses, and base our computation on these idealised forms, the ratios will not differ greatly for the actual shapes.

From Table II it is clear that the effect of particle form is small compared with that of particle size.  $\eta$  is taken at 470 dynes/cm. and the contact angle is assumed to be zero.

### 9.—RECENT DEVELOPMENTS.

De Philly<sup>12</sup> (1937) has shown that by ensuring intimate contact between all the gold particles and mercury, almost the whole can be extracted, even "free" and "floating" gold. The rich amalgam falls to the bottom of the vat; the process works better with dry ore, but can be used also with pulp.

It is right to record that table amalgamation, as described in textbooks, is obsolescent—"The possibilities

of loss by theft, the increasing cases of mercurial poisoning of the workmen, and the lock-up of gold on the plates, led to the substitution of corduroy . . . placed on stationary tables." The pyritic concentrate obtained by washing this corduroy at four-hour intervals is dressed on a reciprocating (Wilfley) table, and the gold-rich fraction is amalgamated. "About 50% of the total gold content of the ore, plus 5,000 oz. of csmiridium, are recovered annually on the Rand from corduroy concentrate." After passing the corduroy tables, the gold ore is cyanided. Nearly 13 million ounces of fine gold was produced in South Africa in 1939, about 14 million in 1940.<sup>13</sup>

The residue of gold in the ore is, of course, in the form of finer particles which do not amalgamate so readily, but are particularly suitable for the cyanide treatment by which they are recovered.

In parts of U.S.A., too, a coarse canvas floor, which entraps the larger particles of gold, has replaced the amalgamation table; and it is not unknown for the prospector to use, quite successfully, his coarse woollen blanket to assess the potentialities of a placer. Here the wheel has come a full circle, and we are returned almost to the exploits of those Caucasians, who, according to Strabo, gave rise to the myth of Jason's expedition with his Argonauts to capture the golden fleece of Colchis. ". . . and there is no new thing under the sun."—Ecclesiastes.

(Grateful acknowledgement is made of the ungrudging assistance rendered by Miss C. A. Ewing, M.A., Librarian to the College, during preparation of Pt. I. of this paper.)

### Re-Rolled Rail Steel Production in the United States

PRODUCTION of re-rolled rail steel has been increased more than 80%, according to Mr. John T. Whiting, director of the steel division of the United States Production Board, as a result of a carefully planned programme begun early in 1943. Twenty-two rail steel mills in the country produce steel bars and small shapes by re-rolling used railroad rails. Five of them are operated by large companies with integrated steel plants, the remainder by small firms specialising in this type of production. Late in 1942, as a result of various limitation and priority orders, many of these mills were ready to close for lack of business.

Regulations were issued permitting the use of re-rolled rail steel where other steel was prohibited, as, for instance, for such important products as farm fence-posts and military steel cots. Steps were taken to promote a greater use of rail steel for concrete reinforcing bars, army entanglement posts, farm implements, small tools, etc. This programme resulted in a steady increase in the output of rail steel mills, shipments in January, 1944, totalling 43,019 tons, compared with 23,716 tons in January, 1943.

<sup>12</sup> De Philly. *Rev. l'Ind. Min.*, 338, p. 102, 1937.

<sup>13</sup> *Official Year Book of the Union of South Africa*, 1940.



# Recent Developments in Steelmaking

By J. Edmiston

*While considerable attention has been given to the whole field of alloy steel consumption and to schedule the various compositions and properties which apply to different uses, steelmakers have concentrated on maximum production of improved quality steel. The author reviews some aspects of production and directs particular attention to the increased application of electric furnaces and to improvements in the production of clean steel.*

**S**INCE the war began, the ever-changing demands of the Services and the need for conserving strategic materials have presented the steel industry, both here and in the U.S.A., with many problems which demanded a combination of engineering and metallurgical skill to solve. Perhaps the most outstanding development is the great extension in the manufacture of electric steel, an increase which has by no means reached finality, but which at the moment seems to be below the demand. Both in this country and in the United States, strenuous efforts have been made, and are being made, to obtain the maximum return from all the plants in production. This is true of the large open-hearth installations as well as the purely electric units.

Past achievement in this direction had taken two distinct methods of approach. One was to concentrate the demand, as far as possible, for all high-grade ordnance steels and similar materials on the electric plants, leaving the commoner types to the open-hearth units. The other approach was to extend the use of the electric furnace as a refiner of liquid steel produced from rapidly working melting units or Bessemer vessels. Both these methods, under suitable conditions, have shown very great advantages in respect of quality, tonnage and cost, and it is likely that the lessons of the war, learnt at great cost, will be applied to meeting the post-war demand for high-grade steels that is sure to arise.

## Electric Furnaces

The most outstanding development of the electric furnace itself is the steady growth in capacity, some of the latest units to be installed in the United States being of 100 tons. Units of 60-80 tons are relatively common. Such furnaces, it has been amply demonstrated already, make but a poor showing in comparison with the equivalent open-hearth from a melting rate and cost point of view, and hence are not favoured as primary producers. Their advantage, however, far outweighing any other consideration, lies in their ability to do what the open hearth cannot possibly do, carry the refining and deoxidation of the melted metal to a point far beyond anything possible in any other type of furnace. In this respect, they have no competitors. Their chief application is therefore in the refining of steel produced by other less costly melting methods, thus attempting to obtain both high quality and tonnage, ideas which have hitherto been somewhat opposed.

## Two-Furnace Process

Arranging a large modern steelworks for production on these lines calls for considerable ingenuity, if all

departments are to be effectively interlocked. First consideration must be given to the means whereby rolling mills and forges may be supplied with a regular flow of ingots so that stand-by losses will be avoided as far as possible. One large plant uses a basic-lined 200-ton tilting furnace to feed an 80-ton electric refining furnace, also basic lined. Preliminary melting is accomplished in the large furnace and 80-ton charges are drawn off by the electric furnace as required. The large furnace is thus little more than an active mixer, and serves only to decarburise and dephosphorise the steel. The tilting arrangement of the large furnace allows any quantity of liquid metal to be drawn as and when desired, and as each charge is drawn off, an equivalent amount of pig iron and scrap are added, with, of course, regular renewals and adjustment of the slag. The metal in the mixer is thus always maintained low in carbon and phosphorus, and forms an ideal basis for building up high-grade alloy melts in the electric furnace. Such a plant has the advantage that it can readily deal with the varied and often nondescript class of scrap which is comparatively easily obtained.

The transfer of the liquid metal from the mixer to the electric furnace is accomplished by a standard type of ladle, the metal being run into the electric hearth through a bottom runner to avoid carry over of mixer slag. It is necessary to keep the slag from the mixer out of the electric furnace, since it is rich in phosphorus, which under the conditions of electric refining would return to the metal. The mixer melt, of course, is always highly oxidised and may even be "wild," so that some preliminary "killing" with silicon, partly in the ladle and partly in the electric furnace, is first accomplished. When this has been satisfactorily completed, it is safe then to build up a highly basic carbide slag for deoxidation and elimination of sulphur. Alloying elements, such as nickel, molybdenum and copper, are added early in the heat, since they remain in the steel under all conditions of melting. Chromium and manganese and similar readily oxidised elements are only added after deoxidation is well advanced. There is thus no loss of these latter elements. Final elimination of gas dissolved in the steel, as a result of various chemical reactions during deoxidation, is completed by means of ferro-silicon added late in the process, leaving only the carbon to be adjusted to specification.

From an electrical point of view, a large electric furnace working regularly with liquid metal, is a comparatively steady load which can be supplied cheaper than an equivalent furnace melting cold scrap. Few power companies would look with unconcern on any

proposal to work such large furnaces with cold scrap since the fluctuation in power during the melting period is always violent and often enormous. Great surges of the order of many thousands of amperes in the supply lines could hardly be tolerated. Even if the plant were sanctioned, the cost of current per unit would be certain to carry such heavy penalties as to be uneconomic. Once a liquid bath is obtained, however, the picture is reversed, and the electric furnace works as regularly as any other large equipment. From this point of view alone, the advantage of the two-furnace equipment is evident. Thus, using the hot-metal process, considerable economy can be realised in electrical plant, since power demand is only of the order of 150 kva. per ton, the time for refining a large charge being about  $4\frac{1}{2}$  hours.

In spite of the many advantages of the two-furnace process outlined above, it is unable to deal economically with every type of steel scrap. If the scrap is known to be highly alloyed with chromium and manganese, the greater part of these elements would be lost to the mixer slag and would require replacement with valuable ferro-alloys. For this reason, it has been found more expedient to melt selected scrap of this kind in much smaller electric units with a proportion of dead soft mild steel scrap to lower the carbon content of the melt, to allow of deoxidation and subsequent adjustment. This, of course, amounts to regular "dead-melting" practice, and is largely followed in the recovery of stainless and high-alloy tool steel scrap.

Electrical considerations, as previously indicated, limit the furnace size, which is able to deal with such special types of scrap, cold-melting reaching its economic limit under present conditions at about 30 tons. Since all the melting is conducted in the electric furnace as well as the refining, the kilowatt-hour demand is of course much heavier, and consequently costs tend to increase rapidly with tonnage. In spite of this, however, this procedure is widely favoured in the recovery of the more valuable type of scrap.

In all the processes involving the use of the electric furnace, apart from the efficient recovery of valuable alloys, improvement of quality is the main motive for installing the plant. This process offers the possibility of working up ordinary "rolling grades" of steel into first-class forging quality ingots. This statement must not be accepted without certain reservations. It is, for example, manifestly absurd to attempt to make highly alloyed ingots which will show serious defects on subsequent forging or rolling, and yet such a result is entirely possible if due attention has not been paid to the preliminary working as well as the finishing of the charge. The electric furnace is not a "cure-all" which will somehow put everything right. This, fortunately, is becoming much more widely recognised in the industry than hitherto, and as a result, close attention is being given to the whole problem of deoxidation.

#### Open-Hearth or Mixing Furnace

Within the limits of tonnage requirements, the method of working the large mixer from the point of view of oxidation largely determines the final condition of the ingot from the point of view of cleanness. Obviously, a "wild" heat from the mixer means more work for the electric furnace to do, and, further, lessens the chance of obtaining a high quality product. Consequently,

although the mixer metal is in the nature of scrap for another furnace, the present tendency is to handle the working of this bath as carefully at least as an ordinary basic melt intended for rolling. Slag control is largely practised, while feeding with ore or scale is restrained to suit carbon requirements. As a result of improved control, this metal seldom, if ever, shows any tendency to wildness, and is thus an excellent starting material for subsequent refining.

#### Bessemer Mixer

Another development, which is really a variation on the mixer process for ensuring a flow of hot metal to the electric furnace, utilises Bessemer converters, basic lined, working on suitable liquid iron from the blast furnace. Since this is an all-hot-metal process, some reduction in costs could be anticipated. In practice, however, these are not so substantial as might be imagined, since they are to some extent offset by the fact that it is by no means easy to synchronise the blast furnace, converters, and electric plant, so that there is no lost time. At the same time, the Bessemer melt has always a tendency to be wild on casting, with the result that the steel, even after treatment in the electric furnace, is more likely to be rather less clean than is desirable in this class of ingot.

The electrical costs in the Bessemerising process are not any less than in the two-furnace method, while other fuel costs may be at least as great, since it is the usual practice to maintain a "tank" furnace of 400 tons to 500 tons capacity as a primary receiver for the molten iron from the blast furnaces. This is fired with gas to maintain the temperature of the iron, and also to accomplish a certain small amount of refining.

About the only justification for processing steel in this manner would be the prior existence of blast-furnace and Bessemer plant already working in a large steel mill, where the hot iron, under favourable conditions, might be cheap enough to be economic. In the majority of steel plants, especially those on this side of the Atlantic, the direct processing of iron in this manner would most probably prove disappointing.

#### Metallurgical Aspects

Since the ultimate end of all these steelmaking practices is to produce high-grade steels in unusually large quantities, it will be instructive to examine the metallurgical foundation on which they rest. It is comparatively easy to arrange the production of large quantities of soft low-carbon steel from basic furnaces. The rate of refining and the final carbon content at which the metal is tapped, however, decide just how much ferrous oxide is dissolved in the metal. High rates of elimination near the end of the refining stage, especially if associated with low manganese content, are certain to produce "wild" metal. Active heats of this description can of course be quietened with silicon and aluminium, but it is virtually impossible to clarify such steel of the finely divided silicates and alumina by any after-treatment, no matter how lengthy. These inclusions are so small they refuse to rise to the top of the liquid and remain permanently dispersed in the steel. The presence of such inclusions has a profound effect on the mechanical properties of the cast, imparting pronounced directional properties to the rolled or forged ingots. While such ingots may be mechanically satisfactory in a longitudinal

direction, they usually fail completely in the transverse direction. High quality ingots are often forged into products requiring primarily high transverse strength, so that failure in this respect may prove costly. The remedy is, of course, to strike a balance between over-oxidation and rapid succession of heats on the one hand, and more careful working with a necessary lowering of output on the other. Past experience has amply proved that the latter course is really the more productive in the aggregate, taking into account the number of scrapped ingots at a later (and more expensive) stage of the process.

### Clean Steel

When the liquid steel from the open-hearth furnace has been transferred to the electric unit, it becomes the business of the furnaceman to undo all the harm done by his counterpart on the open-hearth stage. The success of the cast, both in regard to cleanness and composition rests entirely on his labours. The function of the electric furnace is to deoxidise the steel by means of a carbonaceous slag. Some of this carbon is in the form of calcium carbide. Under these conditions the ferrous oxide is readily reduced, and the product of this reaction leaves the metal as a gas, carbon monoxide. Because of the tendency of the electric bath to be hotter under the arcs than at the bottom, the deoxidised steel immediately under the slag will naturally tend to stay there. It thus becomes the head melter's duty to ensure that the whole mass of metal in the furnace comes adequately under the influence of the carbide slag. As may be imagined, this is no light task in a 100-ton bath. Consequently, deoxidation is necessarily slow. It is, nevertheless, the only way to produce clean steel.

### United States Bauxite in 1943

BAUXITE mine production and mine shipments in the United States in 1943 were more than double the previous records of 1942 and were almost seven times the 1941 totals. Output in 1943 was estimated at 7,026,040 short tons (dried bauxite equivalent), compared with 2,966,221 tons in 1942, while mine shipments were estimated at 6,752,250 tons in 1943, compared with 2,768,343 tons in 1942. Although data on imports of foreign ore are not available, a substantial addition to the total supply resulted from imports which reached a new all-time record, more than 60% greater than in 1942. United States production and imports in 1944 are expected to be considerably less than in 1943, owing to the recent cut in alumina and aluminium production announced by the War Production Board and to the large stocks of bauxite held by the Metals Reserve Co. and private industry.

Of the estimated 1943 production, Arkansas contributed 97% and Alabama, Georgia and Virginia the remaining 3%. Throughout 1943 bauxite containing less than 15% silica was under allocation by W.P.B., while ore averaging more than 15% silica was not restricted as to use. Production of low-silica bauxite (containing less than 8%  $\text{SiO}_2$ ), which was limited to the most essential uses, totalled 2,329,600 tons, while output of high-silica restricted (8 to 15%  $\text{SiO}_2$ ) and unrestricted ore totalled 4,228,000 tons, and 468,440 tons respectively.

By proper deoxidation under a carbide slag, it is possible to deoxidise regularly to very low limits, 0.002% FeO having been achieved in commercial practice. Such quantities of oxide can only produce negligible amounts of inclusions. Such inclusions as appear in ingots made in this manner, are mechanical in origin—e.g., pieces of refractory from ladle, runners and nozzles—and are usually large in size and obviously accidental. In the larger ingots they will most frequently be found in the sink head. In small ingots there is a chance of gross inclusions being trapped in the comparatively rapidly freezing metal. The steps which are taken to obviate this ever-present danger are simple. The large steelworks concentrating on this class of output have a casting-pit technique which, in essence, is scrupulous cleanliness. Moulds are cleaned and fettled with a good deal more than ordinary care. All refractories and similar types of stocks are purchased to close specifications and constantly checked. Finally, when the moulds are set in the pit, they are kept covered until just prior to use. In some cases the atmosphere is excluded during teeming by means of a blanket of nitrogen gas injected into the mould. To the ordinary steel producer, some of these precautions may seem a little far-fetched, but the fact remains that they have been found essential in the production of the best quality steel. Looked at from a business point of view, the little extra labour involved is really an excellent insurance against a valuable forging being scrapped when it reaches the stage of machining. Quite apart from the monetary loss, which may be considerable, the loss in terms of man-hours at the present time may be even more serious.

Consumption of bauxite by the various industries broke all records in 1943, exceeding that in 1942 by 89%, and is estimated to have totalled 5,340,000 tons, compared with 2,820,525 tons in 1942. The amount used in the alumina industry was 4,771,000 tons or 89.3% of the total; abrasive and refractory industries, 347,000 tons or 6.5%; chemical industry, 179,900 tons or 3.4%; and other industries 42,100 tons or 0.8%.

Stocks of bauxite owned by the Metal Reserve Co. and by private industry increased from 1,759,597 tons on December 31, 1942, to an estimated 4,928,000 tons on December 31, 1943, a gain of 180%. At the November, 1943, rate of consumption stocks of ore at mines, processing plants, consuming plants and Government stock depots on December 31, 1943, were equivalent to more than nine months' supply. At the reduced consumption rate expected during 1944 these stocks probably represent at least one year's supply.

### The Royal Aeronautical Society

THE following is a list of the Council of the above Society for 1944-45: Mr. E. J. N. Archbold, Air-Commodore F. R. Banks, Mr. A. C. Brown, Mr. S. Camm, Mr. W. C. Devereux, Mr. G. H. Dowty, Mr. A. G. Elliott, Mr. S. H. Evans, Major F. B. Halford, Major R. H. Mayo, Mr. N. S. Muir, Mr. R. K. Pierson, Mr. G. E. Petty, Mr. N. E. Rowe, Mr. A. E. Russell, Sir Francis Sheldermine, Major B. W. Shilson, Sir Oliver Simmonds, Mr. R. S. Stafford, and Mr. C. C. Walker.



# Thermocouple Method for the Measurement of Liquid Steel Casting-Stream Temperatures

By D. A. Oliver, M.Sc., F.Inst.P., and T. Land, M.A.

(Research Department, Messrs. William Jessop & Sons, Ltd., Sheffield.)

*A new method of measuring the true temperature of liquid steel in the casting stream is described in a recent paper,\* which is reproduced in the present article. The application of the method is illustrated by two investigations, the results of which showed gratifying consistency and the procedures proved simple and reliable.*

**T**HE influence of casting temperature on the quality of ingots and foundry castings is widely recognised, and in many steelworks and foundries routine observations on the casting stream are made with optical pyrometers. Such measurements are made for record purposes rather than for temperature control, so that the repetition of unsuitable temperature conditions may be avoided.

The optical pyrometer has given good service in the foundry with which the authors are particularly concerned, but its accuracy is severely limited. The temperature measured with an optical pyrometer is not the true temperature of the metal, and a correction of about  $130^{\circ}\text{C}$ . is usually added to the pyrometer reading. The reading obtained depends not only on the temperature of the metal, but also on such factors as the steel composition, the degree of oxidation of the surface and the smoke which may be present between the metal stream and the observer. It is clearly desirable to devise a more accurate method of measurement, either to supersede the optical pyrometer or at least to give under experimental conditions more exact information about the correction to be applied to optical-pyrometer readings in different circumstances.

When the metal is poured over the lip of a ladle, the normal quick-immersion technique using a platinum thermocouple is quite satisfactory, and accurate temperature measurements can readily be made. When the metal is bottom-poured, however, the velocity of the moving stream is such that any tube put into the stream merely splays metal in all directions. It is clearly necessary to measure the temperature at some point where the metal flow is unimpeded and is constricted by a short tubular ring. The present paper describes the development of a method based on this principle.

## Early Attempts to Measure Casting-Stream Temperatures

The first "temperature ring" was made of arc-furnace electrode graphite, and the details are shown in section in Fig. 1. The thermocouple was protected by a silica tube, which projected about 1 in. from the graphite in the narrow part of the funnel. The graphite ring was mounted in a stout steel frame, so that it could be placed on a casting-box over an ingot for the preliminary experiments. The greater part of the ingot was cast straight through the casting-box, without passing through the graphite funnel; when the metal

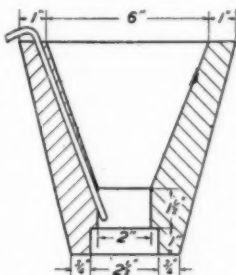


Fig. 1.—Section of graphite funnel with thermocouple in position.

in the ingot reached the ingot head, the ladle was moved across and the remainder of the steel was cast through the "temperature ring." The thermocouple was connected to a Tinsley high-speed amplifier and recorder, and the record obtained is shown in Fig. 2, which also records the previous dip in the furnace and (unsuccessfully) in the launder.

The results were most encouraging, although several possible

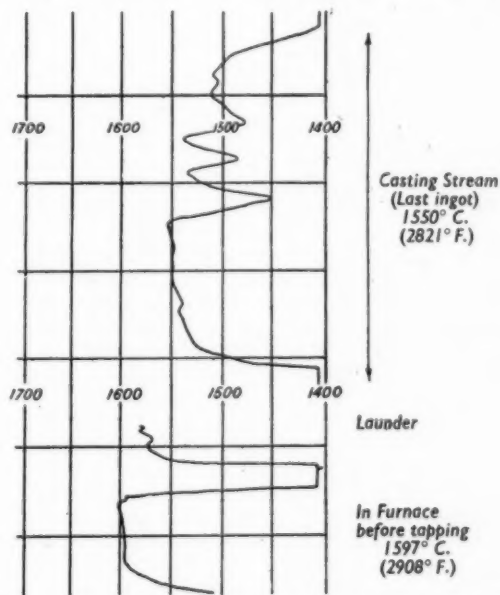


Fig. 2.—Tracing a first record of true casting-stream temperature.

improvements were apparent. The silica sheath survived intact, although it was somewhat bent, and the thermocouple was undamaged. The graphite ring was considerably eroded by the flowing metal, and some alternative material seemed to be indicated.

As a result of the first experiment a new assembly was tried. It consisted of a "trumpet top" attached to a 2 in. ladle nozzle. This combination was built into a sand mould in place of the usual runner-box.

\* Paper No. 5/1943, of the Steel Castings Research Committee, submitted by the Foundry Steel Temperature Sub-Committee and published by the Iron and Steel Institute, March, 1944. (Advance copy.)

The nozzle was drilled with a  $\frac{1}{4}$  in. hole at an angle of about  $35^\circ$  to the horizontal, and a silica tube containing the thermocouple wires was introduced through the hole, protruding  $\frac{3}{4}$  in. into the casting stream. When the steel was cast the silica sheath was broken and no reading was obtained. However, later experiments suggested that assembly with slight modifications might still prove suitable for casting-stream measurements on uphill cast ingots.

### Final Design of Apparatus

The early attempts suggested a design which has given very good results. The basis was a standard runner-box, rammed with "compo," consisting of a conical refractory lining,  $\frac{3}{4}$  in. thick, 10 in. deep, tapering to a minimum internal diameter of  $2\frac{1}{4}$  in. and provided with a cylindrical cast-iron case. The refractory lining was drilled 1 in. from the bottom with a  $\frac{1}{4}$  in. hole at an angle of about  $35^\circ$  to the horizontal, and a 1 in. hole was drilled at the appropriate point in the cast-iron case. The two components of the runner-box were assembled

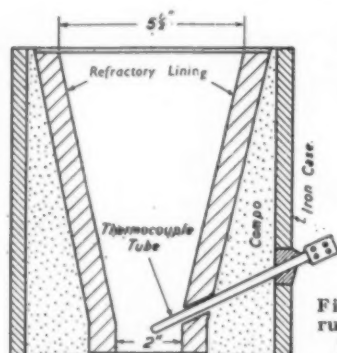


Fig. 3.—Section of runner-box adapted to take thermocouple.

with a steel rod in place of the thermocouple tube, rammed with compo and dried out. The complete assembly is shown in section in Fig. 3.

The thermocouple tube was a silica sheath  $4\frac{1}{2}$  in. long, 6  $\frac{1}{2}$  mm. in external diameter, and 0.7 mm. in wall thickness. The platinum/platinum-rhodium thermocouple wire was 0.5 mm. in diameter and insulated in fine twin-bore silica tubing. The head of the thermocouple unit was a standard two-way porcelain connector cemented to the silica tube. The thermocouple unit could be placed in the runner-box just before casting; it was held in position with "Sairset" cement. About  $\frac{3}{4}$  in. of the silica tube protruded into the casting stream. It was quickly found advisable to cover the thermocouple head and about a foot of the compensating lead attached to it with asbestos tubing to protect them from splashes of hot metal.

It was found that about two out of three determinations were satisfactory with this arrangement, the chief cause of failure being that the ladle operator sometimes interrupted the casting stream during casting, so that the thermocouple did not reach a steady temperature. Occasionally the silica tube broke or the bending of the tube caused a short-circuit in the thermocouple, but the majority of observations were quite satisfactory. Typical records are shown in Fig. 4 and 5.

A conical refractory lining as used in the runner-box has been fitted in the steel frame and used successfully to measure the casting-stream temperature during the

casting of an ingot. A difficulty which sometimes arises in such measurements is that the swinging of the ladle may cause the thermocouple to be momentarily exposed every few seconds, so that it never reaches a steady temperature. This trouble can be overcome by steadily moving the ladle with long poles, as is usually done in the foundry.

**Accuracy.**—The accuracy depends first on the thermocouple being immersed in the liquid steel for a sufficient time to enable it to attain a steady temperature. In Fig. 4 the time (12 secs.) was scarcely long enough, but in Fig. 5 15 secs. sufficed to give a perfectly satisfactory record. It appears that the method in its present form is applicable only to castings of greater weight than 5 cwt.

Another possibility of error is that the refractory lining may cool the steel before it reaches the thermocouple. Approximate calculations suggest that the cooling is unlikely to exceed  $3^\circ\text{C}$ . for the 7-cwt. castings investigated, and is more likely to be less than  $2^\circ\text{C}$ . This source of error has therefore been neglected.

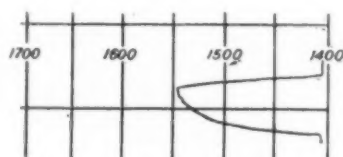


Fig. 4.—Tracing of first record of casting-stream temperature, using adapted runner-box.

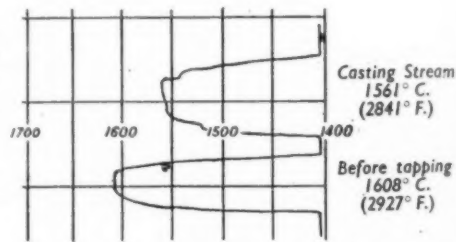


Fig. 5.—Tracing a typical pair of records, showing furnace temperature and casting-stream temperature.

In quick immersion temperature measurements in the furnace it is usually considered necessary for the silica sheath to be immersed for at least  $1\frac{1}{2}$  in. from the hot junction to obviate errors due to heat conduction towards the cool part of the sheath. The greater efficiency of heat transfer in a fast-moving stream appears to reduce this depth of immersion considerably, and  $\frac{3}{4}$  in. of tube protruding into the flowing stream appears to be adequate. The accuracy of the combined amplifier and recorder is of a high order ( $\pm 2^\circ\text{C}$ ). The constancy of the amplification depends only on the permanence of a single resistor, and the overall precision is checked by reference to a Weston standard cell incorporated in the amplifier.

### Applications

To illustrate the value of the method a series of measurements was made using the "temperature ring," and simultaneously observations were made with a calibrated disappearing-filament optical pyrometer. Temperature measurements were also made in the furnace before tapping. In this way the emissivity and the ladle cooling of the steel were measured, two quantities of particular interest to the Foundry Steel Temperature Sub-Committee.

The measurements were made on a nickel-chromium-molybdenum steel which was, at the time of these experiments, in regular production under closely standardised conditions. A typical analysis was as follows:—

	By weight,		By weight,
Carbon	0.40%	Nickel	2.5%
Manganese	0.60%	Chromium	0.80%
Silicon	0.25%	Molybdenum	0.65%

The steel was made in a 12-ton basic electric-arc furnace, and cast from a ladle lined with fireclay-bricks. The metal was poured from the bottom of the ladle through a magnesite nozzle with a fireclay stopper end, previously boiled in tar.

TABLE I.—TEMPERATURE MEASUREMENTS IN THE FURNACE AND DURING CASTING.

Cast No.	Time.	Furnace Dip, °C.	Power, Kw.	Tapped, Time.	Castings.			Remarks.
					No.	Ring Couple, °C.	Optical °C.	
A498	11-18	1625	—	—	3	1560	1435	Ladle about 600° C.
A510	11-15	1600	1050	11-28	3	1570	1422	
A509	11-56	1623	600	12-12	3	1550	1390	
A528	9-55	1592	1000	10-25	3	1560	1420	
	10-06	1619	1000		6	1562	1420	
C429	11-39	1580	1500	11-53	3	1560	1425	
	11-50	1602	1500					
A537	11-46	1610	900	12-03	3	1555	1438	0.30% carbon
	11-56	1603	1250					steel.
A539	13-03	1560?	1400	13-22	5	1562-1563	1418	0.30% carbon
	13-15	1615	1200					steel.
A541	11-25	1580-1592	1200	11-47	3	1555	1420	
	11-36	1617	750		7	1555	1415	

The optical pyrometers, manufactured by the Cambridge Instrument Co. and by Hartmann and Braun were calibrated within 24 hours of each observation against a tungsten ribbon-filament lamp standardised at the National Physical Laboratory. The ladle was heated by a gas burner to a temperature of approximately 650° C. before tapping. The metal was held in the ladle for 10 mins. before casting. The majority of observations were taken on the third 7-cwt. casting.

The experimental results are given in Table I.

**Emissivity.**—The emissivity of liquid steel is the ratio of the radiant energy emitted per unit area of the steel surface to the energy radiated by a perfect black body at the same temperature. Since the human eye in conjunction with the red filter of the optical pyrometer only responds to radiation in a narrow band of wavelengths, the emissivity ( $E_\lambda$ ) with which we are concerned is the "spectral emissivity" at the effective wavelength ( $\lambda_e$ ) of the optical pyrometer. The effective wavelength was approximately 0.65 micron. The relation between true temperature ( $T_{app}$ ) and apparent temperature ( $T_{app}$ ) is given by:—

$$\frac{C_1}{\lambda_e^5} e^{-\frac{C_2}{\lambda_e T_{app}}} = E_\lambda \cdot \frac{C_1}{\lambda_e^5} \cdot e^{-\frac{C_2}{\lambda_e T}}$$

where  $C_1$  and  $C_2$  are Wien's radiation constants. It was not always practicable to make a temperature measurement in the furnace immediately before tapping the metal into the ladle. The relation between the power input to the furnace as indicated on the wattmeter and the rate of rise of temperature had previously been determined as accurately as possible; this relation was used to estimate the true temperature of the metal as it left the furnace. In most cases the furnace was tapped within 10 mins. of the last dip measurement in the furnace, and the estimated temperature change during the period was between 3° and 17° C.

The measurements of the true casting-stream temperature measured by the authors' new method and of the brightness temperature measured optically are correlated in Fig. 6. The majority of the observations lie in the neighbourhood of the line corresponding to an emissivity of 0.38. The only point seriously out of accord is that

for a brightness temperature of 1,390° C. It seems probable that there was interference with the optical reading due to smoke during this observation. The correlation is quite as good as could be expected, merely taking into account the uncertainty of the optical-pyrometer readings, which are rarely reliable to better than  $\pm 10^\circ$  C.

**Ladle Cooling.**—Ladle cooling readings obtained with the alloy steel are set out in Table II, which also includes two results on carbon steels (A537 and A539). The ladle was of normal design, capable of holding 14 tons of molten steel. In these experiments the average content of metal was approximately 10 tons.

TABLE II.—LADLE COOLING READINGS.

Cast No.	Tapping Temp., °C.	Casting Stream Temp., °C.	Ladle Cooling, °C.
A510	1617	1570	47
A529	1620	1550	70
A528	1626	1561	65
C429	1608	1560	48
A537	1615	1555	60
A539	1627	1565	62
A541	1622	1553	67

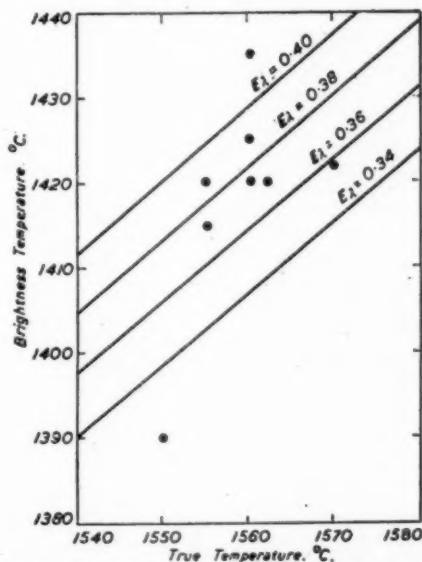


Fig. 6.—Relation between brightness temperature (as measured by optical pyrometer) and true casting-stream temperature for nickel-chromium-molybdenum steel.

The average value of the temperature drop between furnace and ladle was 60° C., the range of variations being 23° C.—i.e.,  $\pm 12^\circ$  C. The authors have pointed out in a previous paper<sup>1</sup> that there is likely to be this range of uncertainty of at least 5° C. in estimating the change in temperature between the last dip measurement in the furnace and the commencement of tapping. The results, therefore, can be considered concordant within anticipated limits.

One of the authors<sup>2</sup> has published a mathematical analysis of the ladle cooling of liquid steel, stating that the figures given in the paper should be multiplied by a constant factor to be determined experimentally. The value of the ladle cooling calculated from the published

<sup>1</sup> Oliver and Land, *Jour. Iron & Steel Inst.*, 1942, No. 1.

<sup>2</sup> Land, *Jour. Iron & Steel Inst.*, 1941, No. 2, pp. 157 P-168 P.



tables is 78° C. for the conditions of the experiments, so that the constant factor in this case is 0.7. It remains to be seen, however, whether this value is equally valid for a wide range of conditions.

### Conclusions

A simple and successful method has been devised for measuring the temperature of the casting stream in the foundry. It can be applied to castings of more than 5 cwt. in weight with only slight modification of standard

foundry practice. It appears essential to employ some type of high-speed temperature recorder in view of the short time available for the measurement. The method appears to be suitable for the investigation of emissivities and the ladle cooling of liquid steels under foundry conditions.

The authors express their indebtedness to the members of the Foundry Steel Temperature Sub-Committee for helpful discussion during the course of this investigation.

## Carbon and Alloy Steels for War Purposes

### A Review of Recent Schedules and Specifications

*In our July, 1943, issue we reviewed the schedules for carbon and alloy steels then in use for war purposes. Since that time a number of new schedules have been issued which are considered in the present article, particular attention being given to the new specifications.*

**I**N an earlier issue,\* a review was made of schedules for carbon and alloy steels for war purposes. These schedules were prepared with a view to making the best use of available materials used in the manufacture of steels, especially alloying elements and, to ensure that they were effectively applied, a considerable degree of rationalisation of carbon and alloy steels was found necessary. This rationalisation, which dealt with steels used in general engineering and with steels used in armaments and wheeled vehicles applied to wrought steels used in the form of bars, billets, light forgings, plates, strip, sheet, tubes and stampings. The work of preparing the schedules was carried out by the Technical Advisory Committee of the Special and Alloy Steels Committee of the Ministry of Supply and the Superintendent Technical Applications Metals Department, Ministry of Supply, and issued by the British Standards Institution.

The first schedule issued was the now well-known War Emergency British Standard Schedule 970 : 1941, which contained particulars of 58 steels, the En steels, 15 of which are plain carbon steels and 43 are alloy steels. Concurrently with the issue of this schedule was issued a companion document, British Standard 971, which was produced by the T.A.C. with the object of facilitating the supply of carbon and alloy steels for war purposes and contained 33 steels, specifications of which nine are for carbon steels and the remainder for alloy steels. A further schedule of service steels B.S./S.T.A. 5 was prepared in 1942 as a statement of the general service requirements for engineering steels to co-ordinate and simplify the material aspect of current wartime manufacture. This schedule was based on the revised form of B.S. 970 issued in 1942, and also took into account the Direction of the Controller, B.S. 970A, 1942, which limited the available types of alloy steels, and enforced the economical use of alloying elements.

Since the issue of these schedules, which were reviewed in detail in the previous article, a number of new schedules have been issued, and these are now given consideration.

### New En Steels

In January, 1943, an amendment No. 1 was issued to B.S. 970 : 1942, containing three additional specifications, Nos. 100, 101 and 102. The first of these was for heat-treated low alloy steel bars for machining, and the other two for carbon-manganese case-hardening steels. In August, 1943, an amendment No. 2 was issued to B.S. 970 : 1942, in which the En 100 steel was revised, and which provided for a new steel, En 110.

The specification for low alloy steel, En 100, is designed to utilise to the greatest advantage the alloy content of steel scrap. The revised specification specified that the steel shall contain 0.35 to 0.45% carbon, not more than 0.5% silicon, 1.2 to 1.5% manganese, 0.5 to 1.0% nickel, 0.3 to 0.6% chromium, 0.15 to 0.25% molybdenum, and not more than 0.05% of sulphur and phosphorus respectively. This steel is suitable for tensile ranges of 45/55, 50/60, 55/65, 60/70, and 65/75 tons per sq. in., according to a limiting ruling section up to 6 in., 4 in., 2½ in., 1½ in., and 1¼ in. respectively. For minimum tensile strengths of 45 and 50 tons per sq. in. the carbon may be permitted down to 0.25%. The heat-treatment for this steel is to harden in oil or water from 830° to 860° C. and temper at a suitable temperature not less than 530° C. Water quenching should not be applied without extra care and only on casts of low limit composition as the steel is essentially one for oil-hardening. The material covered by this specification is the same as that covered by specification D.T.D. 600, and is capable of meeting the test requirements of specification En 16 (manganese-molybdenum steel) for heat-treated bars. It can also be used for forgings and drop-forgings.

B.S. En 110 is for a low nickel-chromium-molybdenum steel, also designed to utilise to the greatest advantage the alloy content of steel scrap. This steel is specified to contain 0.35 to 0.45% carbon, 0.1 to 0.35% silicon, 0.4 to 0.8% manganese, 1.2 to 1.6% nickel, 0.9 to 1.4% chromium, 0.1 to 0.2% molybdenum, and not more than 0.05 each of sulphur and phosphorus. The mechanical properties obtained for this steel after oil-hardening from 830° to 860° C. and tempering at a

\*July, 1943.

TABLE I.—"PERMITTED" ALLOY STEELS.

B.S. En. No.	Type of Steel.	
8	40 carbon (1% nickel maximum, optional)	—
11	60 carbon-chromium	—
12	40 carbon (1% nickel maximum, optional)	—
13	Manganese-nickel-molybdenum	Steels for hardening and tempering 40-100 tons/sq. in. ultimate tensile strength.
16	Manganese-molybdenum	
17	Manganese-molybdenum (higher molybdenum)	
18	1% chromium	
19	1% chromium-molybdenum	
24	1½% nickel-chromium- (molybdenum optional)	
25	2½% nickel-chromium-molybdenum (medium carbon)	
26	2½% nickel-chromium-molybdenum (higher carbon)	Case-hardening steel as Table II.
30	4½% nickel-chromium	
31	1% carbon chromium	
33	3% nickel case-hardening	For nitriding only.
34	2% nickel-molybdenum case-hardening	
35	2% nickel-molybdenum (higher carbon) case-hardening	
36	3% nickel-chromium case-hardening.	
39	4½% nickel-chromium case-hardening	For valve springs.
40	3% chromium-molybdenum	
41	1½% chromium-aluminium-molybdenum	
48	1% chromium	
50	Chromium vanadium	For valves.
51	3% nickel	
52	Silicon-chromium	
53	Silicon-chromium	
54	Nickel-chromium-tungsten	For corrosion or heat resistance.
55	Chromium-nickel-tungsten	
56	Chromium rust-resisting	
56 M	Chromium rust-resisting	
56 A	Chromium rust-resisting (low carbon)	For hardening and tempering.
56 Al	Chromium rust-resisting (low carbon)	
56 AM	Chromium rust-resisting (low carbon)	
57	Chromium Nickel rust-resisting (high tensile)	
58	Austenitic chromium-nickel rust- and acid-resisting	For hardening and tempering.
58 A	Austenitic chromium-nickel rust- and acid-resisting	
100	Low alloy (heat-treated bars for machining)	—

suitable temperature not exceeding 660° C., are 45/55, 50/60, 55/65, 60/70, 65/75 and 70/80 tons per sq. in., for limiting ruling sections up to 6 in., 4 in., 4 in., 2½ in., 1½ in., and 1½ in. respectively. The material covered by this steel is capable of meeting the test requirements of specifications En 16, 17 and 19 for manganese-molybdenum steels and for 1% chromium-molybdenum steel. It is permitted as an alternative to En 17 and 19 for machining bars and as an alternative to En 16, 17, 19 and 100 for forgings.

The two new non-alloy case-hardening steel specifications, En 101 and 102 are for carbon-manganese and carbon-manganese free-cutting steels which have physical properties for which only alloy steels were previously obtainable. Both steels contain 0.12 to 0.18% carbon, 0.1 to 0.35% silicon, 1.25 to 1.75% manganese, not more than 0.06% phosphorus, and not more than 0.06% sulphur, and 0.08 to 0.15% sulphur respectively. The specified core properties are 40 tons per sq. in. tensile strength, 20% elongation, and 40 ft.-lb. Izod impact value minimum for the first steel, and 40 tons per sq. in. tensile strength, 18% elongation and 30 ft.-lb. Izod impact value for the second steel. The steels are primarily intended for oil-hardening from a temperature of 770°-790° C., but they may also be water-hardened.

#### Alloy Conservation

In 1942 there was issued to B.S. 970 a supplementary Memorandum, B.S. 970A, which embodied restrictions placed by the Ministry of Supply on plain and alloy

steels which might be used for the production of various cross-sections and for case-hardening purposes with a view to economising in the use of alloy elements. It also required specific sanction for the manufacture of special alloy and wrought steels outside the grades covered by the selected compositions tabulated in the schedule.

In 1943, a new Direction or Memorandum, B.S. 970B, was issued, based on Schedule B.S. 970 : 1942, which superseded the 1941 edition of the schedule which formed the basis of the first Memorandum B.S. 970A. Unlike the first, it is restrictive only in regard to alloy steels, which for this purpose are those which, by specification, contain any one or more of the following elements:—0.40% or more of chromium or of nickel; 0.10% or more of molybdenum or of tungsten or of vanadium; 10.0% or more of manganese.

En alloy steels 20, 21, 22, 23, 27, 28, 29, 37, 38 and 47 included in B.S. 970 : 1942 are non-permitted. En non-alloy steels may be made and supplied unreservedly.

In this new Memorandum, three tables are given, showing (1) wrought alloy steels "permitted" for parts up to 6 in., ruling section, and the uses for which such steels may be employed; (2) Table 2 of B.S. 970 : 1942, "Steels for hardening and tempering 40 to 100 tons per sq. in. ultimate tensile strength, bars, billets, light forgings and stampings up to 6 in. ruling section," with the addition of En 100; and (3) steels "permitted" for case-hardening. The non-alloy steels En 14 and 15 are included in the first two tables for guidance, but their manufacture and uses are not controlled. The permitted alloy steels dealt with in this Memorandum are given in Table I, together with the uses and purposes for which such steels may be applied.

No restriction is imposed on the use of any of the alloy steels issued for physical properties higher than or for sizes larger than those for which they are specified, but they must not, however, be used for lower physical properties or for smaller sizes. Designers and users are urged to consider most carefully the combinations of properties—i.e., strength, ductility and notch toughness in making their selection of steels, in that by a relaxation in the ductility or toughness requirements, it is possible to provide the same tensile strength in lower alloy or even plain carbon steels or to employ a given steel in a larger ruling section. In some cases alternative steels are allowed for the same ranges of properties and ruling sections. This is done deliberately to accommodate the changing availability of the respective alloys and other circumstances governing supply from time to time.

TABLE II.—CASE-HARDENING STEELS.

B.S. En. No.	Type.	Specified Core Properties.	
		Ultimate Tensile Strength, Tons/sq. in.	Impact Ft./lb.
22	Carbon case-hardening .....	32	40
101	Carbon-manganese case-hardening .....	40	40
102	Carbon-manganese case-hardening .....	40	50
33	3% nickel case-hardening .....	45	40
34	2% nickel-molybdenum (lower carbon) ..	45	40
35	2% nickel-molybdenum (higher carbon) ..	55	26
36	3% nickel-chromium .....	55-65	25-30
39	4½% nickel-chromium .....	55	25

For particular applications of a type of steel, especially where considerations of heat-treatment are involved, it is desirable that the chemical composition of the steel

TABLE III.—TENSILE STRENGTH OF HARD-DRAWN STEEL WIRE.

S.W.G.	Diam., In.	Special First Quality.	High Quality and Standard Quality.
		Tons/sq. in.	Tons/sq. in.
33	0.010 °	170 min.	160 min.
32	0.0108	170 "	160 "
31	0.0116	170 "	160 "
30	0.0124	170 min.	160 min.
29	0.0136	170 "	160 "
28	0.0148	170 "	160 "
27	0.0164	170 "	160 "
26	0.018	170 "	160 "
25	0.020	170 min.	160 min.
24	0.022	165-175	160 "
23	0.024	165-175	150-160
22	0.028	160-170	140-150
21	0.032	155-165	140-150
20	0.036	150-160	140-150
19	0.040	145-155	140-150
18	0.048	140-150	140-150
17	0.056	140-150	140-150
16	0.064	140-150	140-150
15	0.072	130-140	130-140
14	0.080	130-140	130-140
13	0.092	130-140	130-140
12	0.104	120-130	120-130
11	0.116	115-125	110-120
10	0.128 *	110-120	110-120
9	0.144	110-120	110-120
8	0.160	105-115	100-110
7	0.176	105-115	100-110
6	0.192	105-115	100-110
5	0.212	100-110	90-100
4	0.232	100-110	90-100
3	0.252	100-110	90-100
2	0.276	95-105	80-90
1	0.300	95-105	80-90

should be within fairly close limits. The lowest limits generally practicable under manufacturing conditions are therefore given for carbon, manganese, silicon, nickel, chromium and molybdenum, but such limits are not applicable to steel containing over 3% manganese, 6% nickel, 4% chromium, or 1% molybdenum, either separately or in combination.

The only "permitted" alloy case-hardening steels, together with the carbon case-hardening steel En 32, and the two new non-alloy case-hardening carbon manganese steels, En 101 and 102, are given in Table II. The low-carbon 2% nickel-molybdenum case-hardening steel is used to replace 3% nickel-chromium case-hardening steel for gears and other transmission components, and the high carbon-nickel-molybdenum steel to replace 5% nickel-chromium case-hardening steel for gears, pinions, shafts and other case-hardened components. The two nickel-chromium case-hardened steels are used for transmission parts and small arms, mechanism components, and for high-duty gears and heavy roller bearings respectively. Since the latter steel is of high alloy content it should only be used where high tensile strength is essential.

#### Steel for Spring Wire

Services specifications have been issued by the British Standards Institution for spring wire. Three specifications, B.S./S.T.A. 1, B.S./S.T.A. 3, and B.S./S.T.A. 4, deal with special first quality hard-drawn spring wire, high-quality hard-drawn spring wire, and standard quality hard-drawn spring wire respectively. The steel for the first grade of wire must be produced by the electric furnace and should contain 0.75 to 0.85% carbon, 0.5 to 0.7% manganese, 0.3, 0.02 and 0.02% maximum silicon, sulphur and phosphorus, and 0.10, 0.15, and 0.10% maximum nickel, chromium and

copper. Minimum tensile tests for different gauges of the finished wire which should only be used for special applications are given in Table III.

The steel for the high-quality hard-drawn wire is specified to contain 0.65 to 0.85% carbon, 0.4 to 0.75% manganese, and 0.30, 0.03, 0.03, 0.20 and 0.15% maximum of silicon, sulphur, phosphorus, nickel and chromium respectively. This steel must be made by the electric furnace. Alternatively, it may be of special acid or basic open-hearth manufacture when the sulphur and phosphorus may be accepted up to 0.045% maximum each for acid steel, and 0.04% maximum each for basic steel. Minimum tensile tests for different gauges of finished wire of this steel are given in Table III. Material to this specification is intended only for springs subject to exacting service conditions, and its applications should be restricted accordingly. Steel for standard quality hard-drawn wire is specified to contain 0.55 to 0.85% carbon, 0.4 to 0.75% manganese, 0.1 to 0.3% silicon, and 0.5 maximum each of sulphur and phosphorus, and to have minimum tensile strength for different gauges as given in Table III.

For all three steels, wire of sizes from No. 13 S.W.G. to No. 1 S.W.G. must give a reduction of area in the tensile test of not less than 3.5%. In addition to tensile tests, torsion and wrapping tests are also specified. In the torsion test a sample of each coil of wire from all or certain gauges must withstand without fracture twisting uniformly a minimum of seven turns in one direction and seven turns back in a length equivalent to 100 diameters for the first two grades of wire, and for the third grade, the standard quality, twisting uniformly a minimum of 20 times in one direction in a length equivalent to 100 diameters. Any material showing seams shall be rejected. In the wrapping test, a sample from each coil of wire of sizes No. 23 to No. 14 S.W.G. must withstand without sign of failure being wrapped with eight complete turns round a mandrel of diameter equal to twice the diameter of the wire and unwrapping seven turns for the first two grades of wire and seven and six turns respectively for the third grade.

#### Substitute Steels

In 1942, when the main sources of tungsten were lost, it became necessary to conserve this element and substitute steels were recommended by the Iron and Steel Control to replace high-tungsten high-speed steels, which were only allowed to be manufactured under licence when it was proved that substitute steels were not available. The two substitute steels recommended at first were 6-6 and 9-4. The former steel contained 5 to 6% molybdenum, 5.5 to 6.5% tungsten, 4 to 5% chromium, and 1.25 to 1.5% vanadium, and the latter steel 8.5 to 9% molybdenum, 3.5 to 4.5% tungsten, 3.5 to 4.5% chromium, and 1.25 to 1.5% vanadium. Last year the use of substitute steel 6-6, which was most generally used, was cancelled, and a new molybdenum high-speed steel 4-6 was substituted, containing 3.9 to 4.4% molybdenum, 5 to 6% tungsten, 4 to 5% chromium, and 1.4 to 1.6% vanadium. Recently a new steel containing 16% tungsten, 1 to 5% molybdenum, and 1½ to 1½% vanadium is recommended which will eventually replace the 4-6 molybdenum steel as this latter material is used up. The treatment for this still is somewhat similar to that for the 18% tungsten high-speed tool steel.



# The Institute of Metals

## Annual General Meeting held in London

**I**N our last issue it was only possible to report the initial proceedings of the above meeting as the printing of the issue was almost complete. It was impossible, for instance, to report interesting points raised by the new president, Dr. Griffiths, when he discussed the activities of the Institute; nor the interesting discussion resulting from the paper on damping capacity. In view of the importance of the meeting, a continuance of the report seems to be desirable, and below we publish some of the main aspects.

### The Activities of the Institute

Among the subjects discussed by Dr. Griffiths in his address (which he did not regard as a presidential address) he dealt briefly with post-war activities and responsibilities of the Institute, on which the Council have appointed an Exploratory Committee. The Council naturally wants the help of as many as possible of the members, and especially does it seek the advice of the younger members.

The results of the Institute's efforts to advance metallurgical science and technology are given at meetings and in the *Journal*, and through them ideas are exchanged on these results and on other problems which await solution. Ideas on the possible improvement of meetings are welcomed, but members were asked not to repeat the oft-repeated admonition to increase the number of "practical" papers. The means of redressing the balance of practical and theoretical papers is in the hands of those who feel the need of the practical papers—namely, members who are in works and who can contribute papers on practical aspects.

Other activities, which Dr. Griffiths referred to as of a domestic character for the benefit of members, were also mentioned but he emphasised that the Institute has a wider responsibility. When it was first formed, one of its main objects was the advancement of the knowledge of metals and alloys, and originally the Institute made itself responsible for supervising actual research, but with the formation of the Research Association of the Non-Ferrous Industry, the responsibility for the organisation of co-operative research passed out of the Institute's hands. This absence of direct control of research does not remove responsibility for encouraging investigations into the materials coming within the sphere of interest of the Institute. Every effort will be made not only to support the Non-Ferrous Research Association, but also research developments sponsored by the Government or by industry to increase the quantity of research being carried out on non-ferrous metals.

During the war period the supply of trained metallurgists has been far below the demand, and much thought is being given to preventing the shortage continuing into the post-war years. The question of supply and training of metallurgists is being examined by a Committee set up by the Department of Scientific and Industrial Research. The Council of the Institute submitted a memorandum giving its views on this important subject, and representatives attended to give

evidence before the Committee. As a result of Governmental and general interest in the supply and training of metallurgists, larger numbers of young men are likely to take metallurgy courses. Apart from academic qualification, representations have been made to the Board of Education proposing that plans be drawn up to bring into existence a National Certificate scheme. Further means of encouraging the study of metallurgy have been suggested, amongst which is a growing demand in the profession for means by which those with experience in the application of science, both in industry and elsewhere, could obtain some qualification the possession of which would indicate the standard of knowledge and experience they had attained.

In conclusion, the president said: "When the war finishes, the world, and our own country, are going to be different places, and when we start our full range of activities we shall need to see that they are in tune with the new conditions. I feel that with the greater understanding by the general public of the importance of science to the well-being of the individual, to industry, to the country, and to the world there may well be a call on Institutes such as ours to play a greater part in national and international affairs, if only in an advisory capacity. We as an Institute are already international in our membership, and I trust not solely national in our outlook. Who dares to say that there is no way in which we can assist in the solution of the complex problems which will face our nation and the world in the early days of peace? We now know—indeed, we have always known—that we are going to win this war. When peace comes, it must not and will not find us and our Institute unprepared."

### Technical Session

In the limited time available it was only possible to discuss one of the four papers which were scheduled for presentation at the meeting, this was the report of investigations on:—

### Damping Capacity at Low Stresses in Light Alloys and Carbon Steel, with Some Examples of Non-Destructive Testing

By the late Dr.-Ing. L. FROMMER and A. MURRAY.

The work described in this paper, which is published in full in the January issue of the *Journal* of the Institute of Metals, and in a substantially abridged form in our last issue, was carried out in the laboratories of High Duty Alloys, Ltd. The investigation was undertaken to establish: (1) A reliable and accurate method for measuring the damping capacity of materials, particularly metals; (2) the significance of the damping capacity as a physical property of the material in terms of other known characteristics; (3) the influence exerted by structural defects, such as cracks and porosity, upon the measured damping, and thus to afford means for non-destructive testing; and (4) the practicability of employing damping measurements as a means of quality

control and inspection of raw material and finished components.

By careful design, and as the result of experiment, it has been found possible to separate excessive external damping losses from the intrinsic damping which it was desired to measure. It has been established that at room temperature the damping capacity of the principal aluminium alloy is of the order of  $10^{-5}$  as expressed by the logarithmic decrement. The measured damping is a constant up to a maximum shear stress of 30 lb./in.<sup>2</sup>.

The damping of aluminium alloys appears to depend upon the degree of precipitation present, being highest for maximum solid solution and lowest in the annealed state.

The damping is markedly increased by small cracks or such porosity as would not normally occasion the rejection of a cast ingot. In some instances localised defects modify the damping at the various harmonics, so that the position of the defect can be estimated. This latter feature depends upon the experimentally determined fact that the torsional damping does not vary over the available frequency range.

The damping of a 0.6% carbon steel has been studied up to a maximum stress of 90 lb./in.<sup>2</sup> and has been found to be  $0.5 \times 10^{-4}$  for the tempered condition and  $0.7 \times 10^{-4}$  for the oil-quenched condition, these values being closely reproduced through successive cycles of heat-treatment. Whilst the damping values found by this technique are comparable with those obtained by other workers employing a somewhat similar technique, they are many times smaller than those found at stresses a few times higher by the Föppl-Pertz technique.\*

In presenting this paper for discussion, Mr. Murray referred to the death of Dr. Frommer, who passed away after the work described in it was completed, and said that in view of the energy and experience which Dr. Frommer put into the work and into X-ray crystallography it was a great pity that he had not lived to present the paper.

### Discussion

Professor F. C. THOMPSON: I should first like to say what a pleasure it is to open the first discussion on a paper read under the presidency of Dr. Griffiths. It is a curious fact that the study of what we now know as damping capacity was initiated in this country about eighty years ago, and by physical means, but our contribution since then, and it has been by no means a small one, has been almost exclusively in connection with tests of a definitely mechanical type. This research, emanating from an English laboratory, is therefore all the more to be welcomed; but it is to be welcomed also for its own sake. It is, so far as I am in a position to judge, an outstanding piece of research in connection with damping; in fact, I think that a very good case could be made out for the view that it is the best piece of work ever carried out on damping, using physical methods of investigation.

I should like to deal particularly with just one fundamental point. All researches carried out on damping by means of mechanical tests have given damping values of the order of 1 or 2% at least, while those from physical tests, both in the present paper and in Germany and America, have given results which are only a mere fraction of this. Most of the results in the present paper, for instance, correspond to a damping capacity as it is

normally calculated (that is, 200 times the logarithmic decrement) of something of the order of 0.003%.

The question at once arises of what is the reason for this enormous discrepancy. There is clearly the possibility that in mechanical tests the energy losses are of the order of possibly 1,000 times the actual damping loss

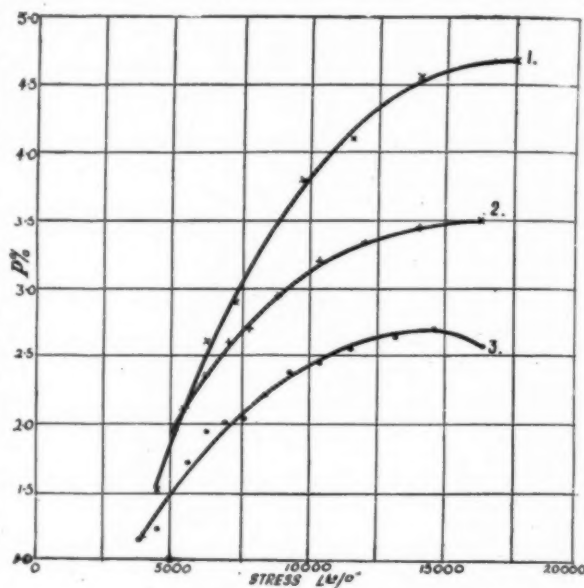


Fig. 1.—Damping capacity—0.2% carbon steel.

1. Grips not fully tightened.
2. Grips fully tightened.
3. Grips modified and fully tightened.

in the test-piece. For some time we have been doing work in the laboratories at Manchester University in a rather elementary attempt to see whether this is at all likely. That errors of considerable magnitude do arise is shown by the curves shown in Fig. 1, all of which

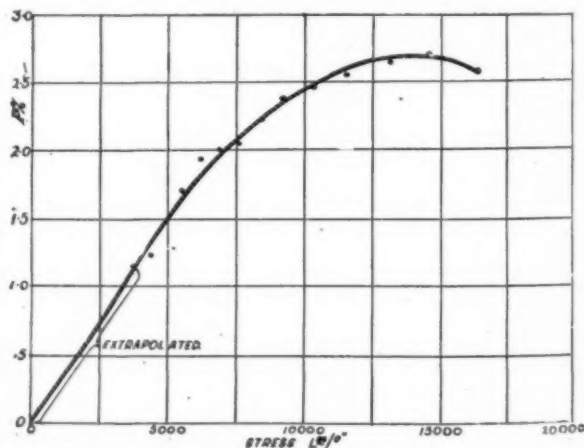


Fig. 2.—Damping capacity—0.2% carbon steel. Extrapolation of curve obtained with modified grip.

refer to the same specimen. Starting off with the middle curve, No. 2, by a series of minor modifications we have been able to pull the damping down and down and therefore make it more and more probable until at the

\* Journ. Iron Steel Inst., 1936, 134, 393.

present time we have got down to curve No. 3. But—and this is a very important matter—the curves appear to be approaching some limiting curve not very much lower than curve 3 so that at the moment there is no explanation of the discrepancy at high stresses of the order of thousands of pounds per square inch from this point of view.

The next possibility is that since the curves fall rapidly as the maximum fibre stress is increased, the differences may be due to the very much lower stress which is normally employed in physical methods of investigation. Fig. 2 shows one of the best of our curves, from which it will be seen how well it extrapolates to something approximating to zero at zero stress. There are in the paper some determinations carried out at a fibre stress of about 700 lb. per sq. in. The extrapolated value from that curve is of the order of 0.2%, but this is still something like 16 times as high as the values recorded in the present paper.

Again, the immediate and perhaps obvious reaction is to say that the mechanical tests are hopelessly inaccurate, but this is just where the results contained in the present paper on steel are so extraordinarily important, and I am very glad that they were included. In the paper it is shown that the damping capacity of a fully-hardened steel is very much higher than that of the same material in the quenched and tempered condition. Now, exactly the same sort of thing has been shown by torsional tests. The differences in the present paper between the hardened and tempered states, if I remember rightly, were something of the order of only 0.005%. It is not possible, it seems to me, to get away from this fact. If the mechanical tests were so hopelessly inaccurate as one might possibly assume, a damping difference of this very, very small order could not possibly fail to be completely masked by the other observational errors, which were of the order of a hundred or a thousand times as great.

It seems to me that there may be another alternative. For some considerable time I have been exercised in my mind on the question of whether physical and mechanical methods of measuring damping were in fact measuring the same phenomenon, and, without committing myself at all to it at the moment, it seems to me that there is evidence that they are not measuring the same thing, and that is to some extent borne out by the evidence in this paper. The authors have shown that, measuring damping capacity as a function of stress, they get, at first, practically a constant value, but that later on it goes up. It is interesting that this was predicted in the very comprehensive paper of the late Dr. Hatfield.

Since this paper was written, I have seen some further work which is being done. Mr. Murray has not mentioned it, but there is good reason to hope that in a short time he may be able to provide the answer to the question as to whether the physical and mechanical tests are measuring the same thing, from the physical side.

The loss of Dr. Frommer was a severe one. The only consolation which one can see at the moment is that the torch which he lit in that laboratory is clearly not extinguished. There are many other points, which might be raised, but I shall deal with them by correspondence.

Mr. L. ROTHERHAM: I have been very interested in what Prof. Thompson has said, and, like him, I feel that possibly the explanation of the difference between the results in this paper and those in his papers and in

Dr. Hatfield's, lies in the fact that it is a different phenomenon which is being observed.

There are two points in the present paper which I should like to emphasise, the first is the conclusion which the authors have reached that the measurement of damping capacity is independent of frequency. There is very good evidence in American papers that that is not the case, although the frequency dependency is largely confined to transverse and longitudinal vibrations. I am not clear in my own mind what is the mechanism of damping in torsional vibrations at these very low stresses. There is a reasonable theory which is being worked out by Zener, with which Mr. Murray will be familiar, dealing with longitudinal and transverse vibrations, in which thermal effects give a very good indication of the properties of different materials. In the case of the transverse and longitudinal vibrations which are referred to in the paper, I think it would be clear, from the dimensions of the samples used by the authors, that any maximum in the curve of frequency against damping capacity would occur at very low frequencies. (I am assuming that they are fairly large specimens in every case.) They are quite outside the range which has been investigated. Therefore, while in the range which the authors have investigated, I think that the conclusion which they have reached is definitely correct, at lower frequencies, which they probably could not investigate with their present form of apparatus, I think we should find the frequency-dependent part of the damping capacity.

The same thing applies, I think, to torsional vibrations when dealing with ferro-magnetic materials. I do not know whether any indication is given in the paper of the variation in damping capacity with frequency of the mild steel which was used.

The main difference, however, between the results recorded in this paper and those obtained with what Professor Thompson describes as the mechanical method is, I believe, the stress difference. We tried to extend the measurements by that form of test to very much lower stresses, and by an improved technique we have managed to carry out tests from 2 tons per sq. in. down to 112 lb. per sq. in. We are still above the normal range of working which the present authors have used. The interesting thing which is observed is that the curve of damping capacity against stress at the higher stresses is a relatively smooth curve, with most of the materials which we have tested, and that continues below 2 tons per sq. in. for a considerable distance. That again is very much like what Professor Thompson indicated. Reference may be made, however, to a curve for an austenitic steel which, at a stress rather below 0.5 ton per sq. in., shows a sudden decrease in the damping capacity, and at 112 lb. per sq. in., the values drop to a logarithmic decrement of  $7 \times 10^{-4}$ . There is no indication as yet that that levels out to a constant value. As with Prof. Thompson's curves, extrapolation produces a straight line going through the origin.

We have had an even more spectacular result than that. Those who read the paper which Dr. Hatfield, Mr. Stanfield and I presented to the North-East Coast Institution of Engineers and Shipbuilders in 1942 will recall that, for stainless iron, very high values of damping capacity have been noticed—in terms of specific damping capacity, values of about 10%. The remarkable thing in relating those tests to lower stresses is that immediately outside the range of stress which we used



previously, the damping capacity begins to decrease in terms of logarithmic decrement. At 112 lb. per sq. in. it was  $500 \times 10^{-4}$ , and at 100 lb. per sq. in. the value decreased to  $50 \times 10^{-4}$ . We have never recorded values in steel as low as those indicated in this paper; the lowest we have ever seen is about  $3 \times 10^{-4}$  for a logarithmic decrement.

The interesting thing about these measurements is that we believe we are beginning to get some idea of what is happening. In the case of stainless iron, for instance, we think that the big increase in damping capacity between 100 lb. per sq. in. and 2 tons per sq. in. is associated with the magnetic properties of the material. That does not apply to the austenitic steels, of course, and we have no idea what happens in those.

I think it is clear that, speaking from our experience with the mechanical form of test, we are not yet able entirely to correlate the results we have obtained with those reported in this paper. In the case of most of the tests which we have done, the curve extrapolated to stresses below 100 lb. per sq. in. definitely appears to be a straight line through the origin. In the case of the stainless iron, there seems to be a tendency for it to flatten, and for a constant value of about  $10 \times 10^{-4}$  to be obtained. I do not think that Mr. Murray has tested any stainless iron, but I should be glad to let him have some stainless iron to test, and I should be interested to know the results.

In conclusion, I should like to associate myself with the remarks of Prof. Thompson with regard to the excellence of this paper. I think that it is the outstanding paper on damping capacity measurements of this type made in this country and published in English, and I think I would include also all the American papers. I find it very interesting indeed, and the main conclusion that I reach is that the procedure which the authors have adopted is one which would be expected to give very low values of damping capacity, and I suggest that that is an excellent start for a test which is designed as a non-destructive test.

A vote of thanks was accorded to the author, who was asked to reply in writing.

### Special Lecture

As mentioned in our last issue, a special lecture was given after the luncheon interval, entitled "Modern Views on Alloys and Their Possible Application," by Dr. W. Hume-Rothery, F.R.S. In addition to members of the Institute of Metals, members of the Iron and Steel Institute, the Institute of Physics, the Physical Society, and the Faraday Society had been specially invited to the lecture, which was well attended. The lecturer dealt with alloys of typical univalent, divalent, trivalent and transition elements, of both scientific and practical interest. He showed that from a knowledge of atomic structures it was possible, in a limited way, to produce alloys with desired structures and properties; an extension of the fundamental work discussed offered great possibilities. An interesting aspect of this lecture was the considerable discussion which followed, those contributing including: Mr. G. L. Bailey, Dr. R. Jones, Dr. Bradley, Dr. A. H. Jay, Dr. H. Lipson, Miss Vera Daniel, Dr. Bruce Chalmers, Mr. H. W. G. Hignett, Dr. K. W. Andrews, Mr. Huddell, Dr. Gayler, Dr. Raynor.

### The Inter-Relation of Age-Hardening and Creep Performance

By C. H. M. JENKINS, D.Sc., E. H. BUCKNALL, M.Sc., and E. A. JENKINSON, M.Sc.

This paper, which was presented by Dr. Jenkins after the special lecture, deals with an investigation on the behaviour in creep of an alloy containing 3% nickel and silicon in copper and form the second part of previous work.<sup>1</sup> Little information on the subject of creep in relation to age-hardening is available, but it has sometimes been assumed that an age-hardening treatment which produces maximum hardness will result in good resistance to deformation, irrespective of the temperature of exposure and time factor.

This is disproved in the present case, in which an investigation has been made into the behaviour under creep conditions of a wrought copper alloy containing 2.4% nickel with 0.6% silicon, after different thermal treatments. These bring about ageing in the alloy and render possible a comprehensive survey of its properties in relation to various amounts of either age-hardening or age-softening in the range 15°-625° C.

The results of tests carried out for short and long times show that at certain temperatures the ability of the alloy to withstand stress varies widely as the result of different heat-treatments. In long-time tests between 230° and 600° C., fully age-hardened material is markedly inferior to fully softened material, but in short-time tests the converse holds.

The changes in microstructure of both stressed and unstressed specimens of the alloy in its various conditions, are compared. It is found that the rupture of tensile and creep specimens in the range 300°-500° C. results from the development of intercrystalline cracks, whereas at lower temperatures transcrystalline fractures are found. In fully softened material there is, however, appreciable lengthening of the crystals before the intercrystalline form of cracking begins to develop.

### Discussion

Dr. H. SUTTON: I should like to pay my tribute to the very careful work carried out by Dr. Jenkins, Mr. Bucknall and Mr. Jenkinson at the National Physical Laboratory, and described in this paper. I feel that there is a great need for information of this kind, and for the basic sort of study which the authors have carried out, to enable us to learn something more than we know at present, which really is rather little, about how to make materials strong at elevated temperatures. The authors' work has shown that at very moderate temperatures we appear to lose a good deal of the benefit seen in quick tests of thermal treatments, which have very large effects on the physical properties of the materials. There are some practical applications in light alloy technology which bring out rather similar effects. In some of our light alloys it has been found in practice that, for service at operating temperatures which take a very long time to have a serious effect on the working properties, something is to be gained by stepping down a good deal below the optimum mechanical properties in the initial material. The recrystallisation temperature is probably a very important point in connection with these studies of creep, and I should like to ask, with regard to the periods with which the authors have been working, what

<sup>1</sup> C. H. M. Jenkins and E. H. Bucknall, *J. Inst. Metals*, 1935, **57**, 141.

is about the minimum temperature at which recrystallisation can be expected to occur in these alloys.

Another point is that, in the case of other series of alloys, apparently we may be able to use them at temperatures higher than the temperature of initial crystallisation because they contain large masses of harder particles than the ground masses.

Mr. E. A. JENKINSON: I think the minimum temperature at which recrystallisation occurs is about 450° C.

The Chairman proposed a vote of thanks to Dr. Jenkins, Mr. Bucknall and Mr. Jenkinson for bringing

this interesting paper before the meeting; he felt that we are really only on the threshold of knowing something about creep resistance and the structural factors which affect it, and work such as has been done by these three authors helps to disperse some of the clouds which are still very thick. A vote of thanks was accorded.

There was no time to discuss the papers by Mr. Fox and Mr. Lardner, and by Prof. Konobeevski, but, as the Chairman pointed out, there is nothing to prevent any member from sending in a written contribution to the discussion.

## Preferred Orientation in Wires and Sheets

### A Discussion Organised by the X-Ray Analysis Group of the Institute of Physics

**X**-RAY diffraction methods are being increasingly used in industry and are producing valuable results. There can be little doubt that more problems will be solved by their aid in the future, but in order that they can be most effectively used it is necessary that the operator shall have had some preliminary training in X-ray crystallography. In no branch of the subject is this more convincingly illustrated than in the study of the orientation of single crystals and of preferred orientation in metals. To attempt such studies without a groundwork of knowledge of crystal projections, particularly the stereographic projection, is to add greatly to the difficulties of an already complicated problem.

These points were emphasised at the conference organised by the X-ray Analysis Group of the Institute of Physics, which was held in Oxford on March 31 and April 1. At the first session the analysis of organic structures was discussed; at the second, the examination of imperfect structures, such as fibres.

Dr. W. H. Taylor opened the discussion in the third and final session, in which the subject was preferred orientation in drawn metal wires and rolled sheets. He began by giving a short account of the stereographic projection, which forms the basis of the most convenient method of representing preferred orientation—namely, the construction of pole-figures.

His exposition was illustrated by means of Fig. 1. The single crystal considered is supposed to lie at the centre of the projection sphere. The normal to any plane is drawn through C, and one such normal CN is shown. All planes are now represented by points on the sphere. Any point, say P, on the surface of the sphere is chosen as the pole of projection, and the final projection may be obtained on any plane (B) perpendicular to the diameter through P. The plane usually chosen is the diametral plane, and the point A where the line PN intersects this is the stereographic point representing the plane originally chosen (that is, the plane perpendicular to CN).

When the specimen consists of a large number of crystals a separate projection is made for each particular plane, each crystal giving rise to one point of the projection. Such a projection is known as a pole-figure, and a series of these will be required to represent a single specimen. The plane of projection is chosen so that it has a particular relation to the specimen; for instance, it is usually perpendicular to the axis of a wire.

Dr. Taylor went on to consider at what stage during cold-work orientation sets in and what mechanism is

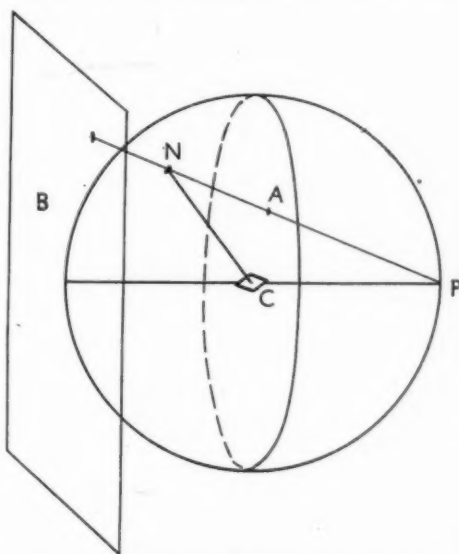


Fig. 1.—Construction of the stereographic projection of a single crystal.

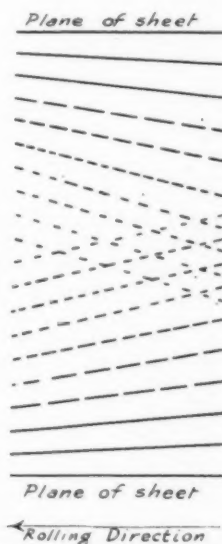


Fig. 2.—Orientation in rolled magnesium sheet.

involved in the process. In the initial stages cold-working results in a decomposition of the crystals into a mosaic structure, and it is not until after this that preferred orientation appears. The stress at this stage is greater than that which would cause fracture of the specimen in a straight tensile test. According to simple theory the mechanism of reorientation involves a modification of the crystals by the processes of slip and of twinning; the processes are controlled partly by the properties of the crystals, and partly by interaction at their grain boundaries.



Fig. 3.—Sample of cross-rolled molybdenum sheet, showing 450 brittleness.



Fig. 4a.—Straight-rolled sheet, X-rays perpendicular to original rolling direction.

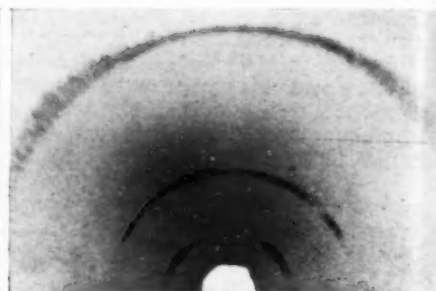


Fig. 4b.—Straight-rolled sheet, X-rays parallel to original rolling direction.

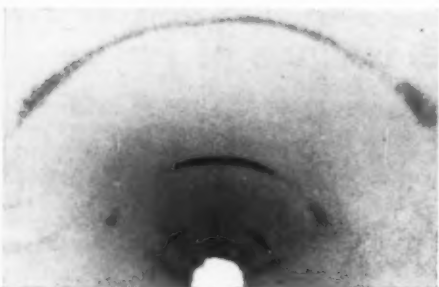


Fig. 4c.—Cross-rolled sheet, X-rays perpendicular to original rolling direction.



Fig. 4d.—Cross-rolled sheet, X-rays parallel to original rolling direction.

All these illustrations are slightly reduced in size and are taken from *J. Inst. Metals*, LXII, No. 1, 1938, p. 208.

A considerable amount of work has been done on the mechanism of slip in single crystals of various metals. In magnesium, slip occurs along the close-packed row lines in the hexagonal structure; at room temperature the slip plane is the basal plane, but at higher temperatures, and for varying directions of stress, other planes can also act as slip-planes. Twinning involves a complete redistribution of atoms throughout a portion of the crystal and nothing is known definitely about the way in which it proceeds. The final state can be deduced by the application of pure geometry.

The study by X-ray methods of preferred orientation in magnesium sheet containing 2% Mn was described. German workers were first to find that there was a tendency for the hexad axis to be perpendicular to the plane of the sheet, and that the scatter about this orientation was greatest in the direction of rolling. American workers found that there was a tendency towards a double orientation in which the hexad axis was inclined at  $15^\circ$  on either side of the normal in the rolling direction. The material showing this double orientation contained calcium. In general, the orientation about the hexad axis was found to be random.

In describing his own experiments, Dr. Taylor said that transmission X-ray photographs showed the double orientation effect in material which did not contain any calcium. This method had the disadvantage that the average orientation over the whole thickness was obtained. A better method was to take surface-reflection photographs, and on etching the surface away in small steps the orientation at different depths below the surface was studied. The surface-reflection photographs were taken with the X-ray beam, both parallel and perpendicular to the rolling direction, and the results showed that at the surface the basal plane

(0002)\* is practically parallel to the plane of the sheet; below the surface the basal plane tends to tilt over until it makes an angle of  $15^\circ$  with the sheet in the rolling direction and deeper down still an orientation of  $15^\circ$  in the opposite direction begins to set in. The results obtained are illustrated in Fig. 2. Orientation effects about the hexad axis have not been determined with certainty.

Mr. H. P. Rooksby described some results of the examination of the metals molybdenum and tungsten in the form of drawn wire and of rolled sheet. The work was undertaken in order to find out whether there was any connection between the preferred orientation and certain undesirable properties of the material as used in lamp and valve manufacture.

He dealt first with the subject of drawn wires, which have been shown to have a texture characteristic of metals with a body-centred cubic structure—that is, a [110] direction tends to lie parallel to the axis of the wire. The scatter about this orientation decreases as the percentage reduction increases, and the texture often differs in perfection between the outer layers and the core of the wire, owing to the mechanism of wire-drawing; in general, the orientation is more perfect in the core of the wire. The deviation from the perfect orientation is affected by grain-size only in the initial stages of the reduction, and the effect of annealing is negligible. It has been shown that there is no change in the texture on recrystallisation during an anneal at  $1,000^\circ$ – $1,100^\circ$  C. Although there is some correlation between preferred orientation and tensile strength, the texture has little practical significance, at any rate as far as the manufacture of lamps and valves is concerned.

\* Square brackets indicate the direction of a normal to the plane, or a zone-axis. Round brackets indicate a plane.



In rolled sheet a further restriction on the orientation is imposed, since [110] tends to become parallel to the rolling direction, and also a cube-face (100) is brought into the plane of rolling. In sheet which has been rolled in one direction only there is a scatter in this latter orientation of some  $10^\circ$  about the rolling direction. It was noticed, however, that sheet that had been rolled in two directions at right-angles was very liable to develop cracks at  $45^\circ$  to the directions of rolling (see Fig. 3). Crystal orientation work on this material was carried out with a view to explaining this phenomenon.

The material used was originally in the form of electrically sintered bars of molybdenum of more than 99.9% purity. The bars were hot-rolled at  $1,200^\circ\text{C}$ . After sand-blasting, the sheet was annealed at  $970^\circ\text{C}$ ., cold-rolled in the same direction, and again annealed. Subsequent cold-rolling, with intermediate annealing was continued (a) in the same direction—"straight rolling"; or (b) at right angles to the original direction—"cross-rolling." The specimen used for X-ray examination was bent into the form of a U and set up so that the X-rays impinged at a glancing angle on the curved surface. The photographs obtained, some of which are shown in Fig. 4, were similar to those given by flat specimens, but more information could be obtained on a single film. All specimens used for X-ray examination were annealed at  $1,050^\circ$ ; the surface layer was removed by etching.

The X-ray photographs taken with the beam both parallel and perpendicular to the rolling direction show that in the straight-rolled sheet continued rolling tends to align the [110] direction into the rolling direction more and more exactly, whereas the cross-rolling does not affect this orientation, but tends to perfect the parallelism of a cube face and the plane of the sheet. This means that the other cube faces will lie perpendicular to the plane of the sheet and at  $45^\circ$  to the rolling direction. Since the cube faces are cleavage planes in molybdenum, their alignment in this cross-rolled sheet would seem to account for the ease with which this material cracks along  $45^\circ$  lines. In addition to the X-ray work, mechanical bend-tests were performed on strip specimens cut at various angles to the original rolling direction. A standard Jenkins' bend-test machine was used, in which a strip of metal about  $\frac{1}{8}$  in. wide is bent backwards and forwards through  $180^\circ$  over a pair of steel jaws ground to an accurate radius, in this case 1 mm.

Results of bend-test figures after different annealing treatments were given, as well as variation of the figures with the angle of the test-piece to the direction of rolling. In the straight-rolled sheet the values show that the fibrous nature developed by rolling results in a much higher bend-test figure for a strip cut parallel to the rolling direction than for a strip cut at right angles to this, while that for the  $45^\circ$  strip is intermediate. For the cross-rolled sheet the difference between the values for the strips at  $0^\circ$  and  $90^\circ$  is reduced, showing a decrease in inter-fibre weakness, but the figures show a minimum at  $45^\circ$  (see Fig. 5).

The results of the work were summed up as follows:—

The molybdenum foil exhibits three types of brittleness—

- (a) Normal inter-fibre weakness, due to lack of cohesion, between fibres developed in the direction of rolling; this is present in straight-rolled sheet.
- (b) Transcrystalline cleavage at  $45^\circ$  to the rolling direction; this is present in cross-rolled sheet where the crystals are in the fully oriented condition.
- (c) Intercrystalline brittleness due to lack of cohesion between grains of the fully recrystallised material; this is present in sheet that has been annealed at  $1,500^\circ\text{C}$ .

Burgers has observed a similar  $45^\circ$  cleavage-plane brittleness in tungsten foil.

Dr. J. T. Randall continued the discussion with an account of published work on the subject of preferred orientation in sheet steel for electrical machinery. The material consisted mainly of iron alloyed with silicon up to 4.1%. Silicon in solid solution increases the resistivity more than any other element that has so far been investigated in detail and so reduces the losses due to eddy currents; it also promotes grain growth and acts as a deoxidiser. On the other hand, it reduces the permeability and the ductility and the production of sheet from it is not an easy matter.

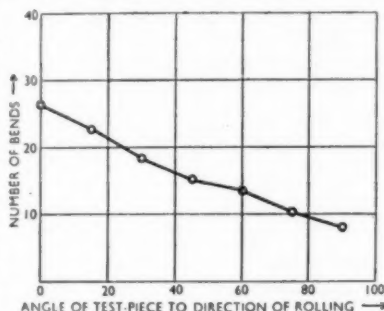


Fig. 5a.—Variation of bend-test figure with angle of test-piece to direction of rolling for 0.10 mm. Straight-rolled sheet annealed at  $1,050^\circ\text{C}$ .

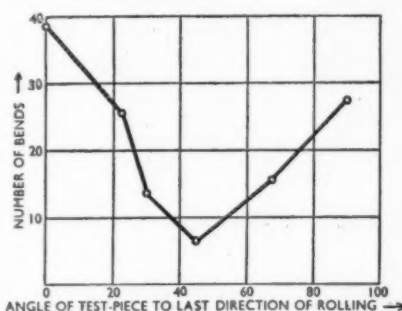


Fig. 5b.—Variation of bend test figure with angle of test-piece to direction of rolling for 0.10 mm. Cross-rolled sheet annealed at  $1,050^\circ\text{C}$ .

From *J. Inst. Metals*, LXII, No. 1, 1938, p. 210.

Dr. Randall emphasised the importance of an exact knowledge of the effect of impurities on the magnetic properties and on the preferred orientation of the silicon-iron sheet. Manufactured sheet contains impurities to the extent of 0.03% carbon, 0.15% manganese, 0.02% sulphur, and 0.02% phosphorus. The most important work on the effect of these impurities is due to Yensen, who showed that carbon and sulphur are particularly harmful when good magnetic properties are required. Carbon, according to Goss, also seems to have a marked effect on the orientation texture of rolled iron sheet.

The advantages which arise from the presence of preferred orientation in silicon-iron sheet were then considered. Fundamental investigations on single crystals of pure iron and of silicon-iron, both of which have a body-centred cubic structure, show that the intensity of magnetisation for a particular applied field varies with direction in the crystal. The magnetisation curve for [100] reaches saturation value for a lower value of the field than for [110] or [111], and thus [100] is

known as the direction of easy magnetisation (see Fig. 6). For transformer construction it is clearly desirable that this direction should lie parallel to the lines of flux, and thus silicon-iron in which [100] lies in the plane of the sheet is required.

The connection between the nature of the glide element for single crystals and the texture of the rolled sheet has by no means been fully worked out. Experimental work on body-centred cubic metals has shown that slip can take place on three different planes, (110), (211) and (321), and the direction of slip is [111]. It appears that the choice of slip plane depends upon the temperature. Some experiments have been done on single crystals of pure iron, which showed that, when a

Etching is necessary in order to reduce the thickness sufficiently to obtain the second type of photograph, and this has the disadvantage that it may act preferentially on grains of a particular orientation. A more serious danger arises when specimen strips are cut for X-ray examination, for the results will be influenced by the cold-work introduced, and the use of etching to remove the cold-worked layer may not be entirely satisfactory.

Dr. Randall concluded with a review of the orientation textures that have been found in iron-silicon sheet. He emphasised that in iron-silicon, unlike molybdenum, the recrystallisation texture after annealing is rarely the same as immediately after the rolling process. Cold-

rolled Goss sheet is manufactured by a twice-repeated process of rolling followed by high temperature annealing at about 1,100° C., and it appeared to be due to this particular process that the unusual and most desirable (110)/[100] texture was obtained. Little X-ray work had been done on hot-rolled sheet, though what little work there was seemed to indicate a (100)/[110]

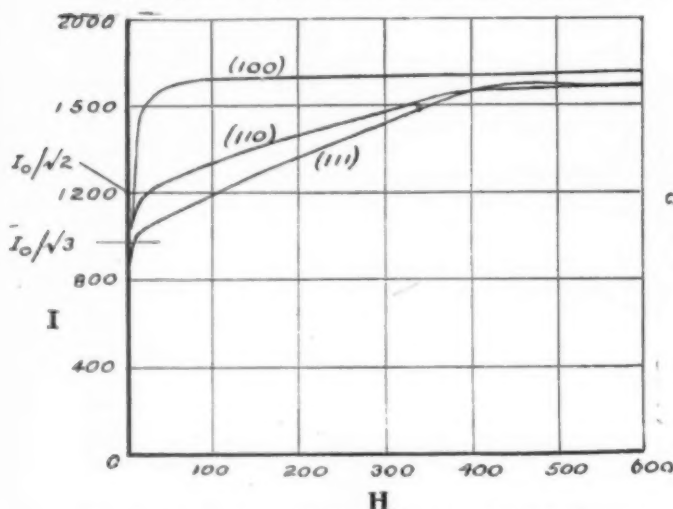


Fig. 6.—Variation of Magnetisation ( $I_p$ ) with field in (100) plane of iron

(From Stoner's "Magnetism and Matter," (Methuen), p. 386, Fig. 61.

single crystal is cold-rolled in a manner simulating the deformation of a grain in a polycrystalline aggregate, it may rotate into the vicinity of one or more of the following positions:—

Rolling plane.....	(001)	(115)	(113)	(112)	(111)	(111)
Rolling direction.....	[110]	[110]	[110]	[110]	[110]	[211]

The final positions of cube poles for such orientations when superimposed on the [100] pole figure for a polycrystalline sheet show remarkable agreement (see Fig. 7).

However, little is known about the effect of rolling conditions, and especially of the effect of impurities on the choice of glide plane, and hence on the resulting preferred orientation.

Methods of investigating preferred orientation in silicon-iron sheet include the X-ray diffraction method as described by the previous speakers, the optical method of etch pits, and a magnetic method which employs an instrument known as a torque magnetometer. In the latter method a plot of torque against the angular position of a disc-shaped specimen is obtained, from the analysis of which it is possible to obtain information concerning orientation.

Returning to the X-ray diffraction method, Dr. Randall pointed out that in order to obtain a complete stereographic study it was necessary to set the specimen so that the angle between it and the X-ray beam could be altered over a wide range. Two types of photograph could be obtained—a surface-reflection photograph and, if the sheet is thin enough, a transmission photograph.

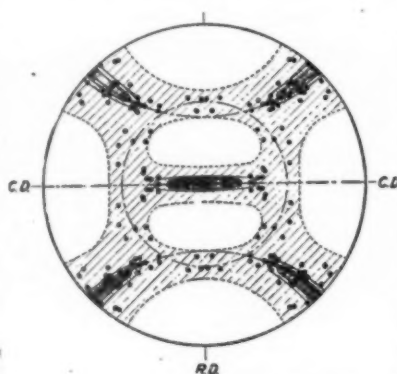


Fig. 7—[100] Poles of 19 single crystals after rolling.

(From "Analysis of the Cold Rolling Texture of Iron," by O. S. Barrett and L. H. Levenson; *Metals Tech.*, Vol. 7, 1940.

texture, together with less prominent (211)/[110] and (111)/[211] textures. It might be noted that in iron containing 1% of carbon Goss had reported a complete reversal of the preferred orientations exhibited in hot- and cold-rolled carbon-free sheet—namely, a (110)/[100] texture for hot-rolled sheet, and a (100)/[110] texture for cold-rolled sheet. It seemed clear that a great deal more work was required to clarify the subject.

In the general discussion which followed, Mr. G. C. Richer, who for 25 years has been in the transformer sheet industry, said that he found Dr. Randall's paper of particular interest. He suggested that there might be disordered regions between the magnetic domains which could not be detected by X-ray diffraction methods; these disordered regions might be expected to have a marked effect on the magnetic properties of the material. He also mentioned that the magnetic permeability curves could be analysed in terms of percentage orientation, a typical result being 80% [100], 15% [110], and 5% [111] parallel to the rolling direction.

Dr. T. L. Richards laid stress upon the necessity for making use of the stereographic projection in all orientation work. He described work which he had done on the orientation of chromium in surface-plating layers. It appeared from glancing-angle photographs that the [111] direction lay perpendicular to the layers, with a random orientation about this direction; this meant that chromium atoms were arranged with the close-packed rows perpendicular to the surface.

Dr. W. F. Berg showed slides of some back-reflection Laue spots from transformer sheet, and suggested that the fine structure they possessed might give some information about slip planes in the crystals. He compared them with similar pictures which he had obtained from rock-salt specimens; in this case the explanation put forward was that the internal fine structure in the Laue spots was due to rotation of crystal fragments on the cleavage planes.

Mr. E. E. Spillett emphasised the importance in practice of preferred orientation in aluminium, but he also pointed out that there is not always complete correlation between the preferred orientation as indicated by X-ray photographs and the physical properties, such as hardness. He showed X-ray photographs of the same specimen in three different states unannealed, partially annealed, and completely annealed. The two first photographs were practically identical, both showing considerable preferred orientation, and the third showed complete removal of the orientation effect; but the hardness in the first two cases showed a considerable difference, whereas in the last two it was the same.

Aluminium has a face-centred cubic structure, and in

the drawn wire [111] tends to become parallel to the wire axis, the orientation being more perfect in the centre. In the production of tubes the orientation depends upon the method of manufacture; if reduction of diameter predominates the [111] direction becomes parallel to the tube axis, whereas if reduction in thickness predominates the [211] direction becomes parallel to the axis; this direction becomes parallel to the rolling direction in aluminium sheet.

Dr. A. Hargreaves gave an interesting account of a moving-film method of recording glancing-angle reflections from a rotating sheet specimen. The sheet was rotated in its own plane, and a stationary screen with a single slit was placed between the specimen and the film, so that X-ray reflection due to only one set of planes was recorded. In this way the difficulty of correlating intensities on separate films, each exposed for one particular setting of the specimen, was obviated. Also, sufficient information was obtained on a single photograph to draw a complete pole-figure on a plane perpendicular to the axis of rotation. The method had been used to show the double orientation in magnesium sheet, an effect which Dr. Taylor had described at the beginning of the session.

## The Scaling Properties of Steels in Furnace Atmospheres at 1,500°C

By A. Preece, M.Sc., and R. V. Riley, Ph.D:

(Leeds University).

*A survey of the scaling characteristics of a selection of steels in furnace atmospheres is reported in this paper,\* which forms part of a more comprehensive study covering the whole range of heat-treatment, forging and soaking pit temperatures found in practice. Some of the results are presented in an abridged form.*

THE composition of the steels used in this investigation are recorded in Table I. All the steels were supplied as forged or rolled bars. The bars were machined to 0.60 in. in diameter; specimens 0.4 in. long were then sawn from the machined bar and polished with 00 emery paper.

The apparatus and experimental procedure was given in an earlier publication.<sup>1</sup> The only modification made in the apparatus for the present survey was the substitution of a gas-heated furnace in place of an electrically heated one. With this gas-heated furnace, a constant temperature zone of 4 in. was obtained at 1,500°C., and with reasonable attention the temperature could be maintained to within  $\pm 5^\circ\text{C}$ .

A mixture of gases consisting of 80% nitrogen, 10% water vapour and 10% carbon dioxide was adopted as a basic furnace atmosphere for this work. It represents roughly the products of complete combustion of producer gas and fuel oil. With suitable additions of carbon monoxide an atmosphere resembling that

TABLE I.  
COMPOSITIONS OF STEELS USED IN THE PRESENT INVESTIGATION.  
The principal elements in the steels are set in heavy type.

Steel.	Composition.									
	C, %	Mn, %	Si, %	S, %	P, %	Ni, %	Cr, %	W, %	Al, %	
0.13% carbon ..	<b>0.13</b>	0.50	0.10	0.029	0.030	—	—	—	—	
1.30% carbon ..	<b>1.30</b>	0.36	0.19	0.014	0.019	—	—	—	—	
5.0% nickel ...	0.14	0.35	0.22	0.031	0.038	<b>5.12</b>	—	—	—	
1% chromium, 24% nickel	0.36	0.63	0.14	0.012	0.022	<b>3.59</b>	<b>0.78</b>	—	—	
4% silicon ....	0.12	0.14	<b>3.84</b>	0.030	0.042	—	—	—	—	
18% chromium, 8% nickel	0.11	0.27	0.19	Low	Low	<b>8.50</b>	<b>17.50</b>	—	—	
18% chromium, 2% nickel ..	0.16	0.30	0.45	0.026	0.032	<b>2.50</b>	<b>17.20</b>	—	—	
12% chromium ..	0.12	0.25	0.54	0.021	0.026	—	<b>12.60</b>	—	—	
3% silicon, 9% chromium ....	0.39	0.38	<b>2.80</b>	0.010	0.020	—	<b>9.00</b>	—	—	
8% aluminium ..	0.12	—	—	Low	Low	—	—	—	<b>8.22</b>	
13% manganese	1.20	<b>13.05</b>	0.49	0.035	0.031	—	—	—	—	
20% chromium, 7% nickel	0.35	0.50	0.50	0.038	0.025	<b>7.00</b>	<b>20.00</b>	<b>4.0</b>	—	
25% chromium, 17% nickel	0.15	0.55	1.54	0.036	0.028	<b>17.50</b>	<b>24.80</b>	—	—	
30% chromium	0.37	0.31	0.37	0.020	0.04	—	<b>29.60</b>	—	—	

\* Paper No. 14/1943, of the Alloy Steels Research Committee of the Iron and Steel Institute. Advance copy, March, 1944.

1 A. Preece, G. T. Richardson, E. Simister, and J. W. Cobb. Second Report of the Alloy Steels Research Committee, Section III, p. 9, *The Iron and Steel Institute*, 1939, Special Report No. 24.



obtained by incomplete combustion of the fuel was produced. Additions of oxygen, on the other hand, gave an atmosphere such as would result from the use of excess air in burning the fuel.

In fuel technology, furnace atmospheres are described as neutral, reducing or oxidising according to whether they are free from or contain either carbon monoxide or free oxygen, respectively. It will be understood that such terms refer only to the composition of the atmosphere and are in no way concerned with its effect on steels exposed to it. In the following text the basic atmosphere described above is referred to as the neutral atmosphere.

#### Plain Carbon Steels

The scaling properties of the 0.13% and the 1.3% carbon steels were very similar in all respects. The type of scale produced and the character of the scale-metal interface were identical in all the atmospheres used in the present investigation; there was, however, a slightly lower rate of scale formation with the high-carbon steel in the neutral atmosphere, but this was not maintained when  $\text{SO}_2$  was added to the atmosphere, and with 0.2% of  $\text{SO}_2$  in the atmosphere both steels gave identical results.

In the sulphur-free atmosphere, the scale on both steels was similar and consisted of two layers. The outer layer was highly crystalline, as was illustrated, and was very easily detached, revealing a finer crystalline inner layer, which could also be removed, though less readily, from the metal surface. With additions of  $\text{SO}_2$  to the atmosphere the scale surface changed gradually from a highly crystalline to a smooth type, until with an atmosphere containing 0.05% of  $\text{SO}_2$  the specimen possessed a flat, crazed appearance. With higher concentrations of  $\text{SO}_2$  the surface showed signs of having been semi-molten, and with 0.20% of  $\text{SO}_2$  a very rough disrupted scale was formed in which the macro-crystalline character of the surface was completely obliterated.

The scales formed on the plain carbon steels in the neutral atmosphere containing appreciable quantities of  $\text{SO}_2$  consisted of a layer of iron oxide separated from the steel by an iron-oxide/iron-sulphide eutectic. The mechanism of scale formation under these conditions proceeds by the solution of iron in the molten sulphide phase at the metal interface and the formation of iron oxide where the molten phase meets the outer iron-oxide layer. A molten phase in contact with the steel at the scaling temperature would thus account for the increased attack. The presence of this oxide-sulphide eutectic was always associated with intercrystalline penetration of the scale into the steel.

In the neutral atmosphere the metal below the scale was decarburised to a depth of approximately 0.04 in. With increasing percentages of  $\text{SO}_2$  in the atmosphere the decarburised band became narrower, until with 0.20% of  $\text{SO}_2$  it disappeared completely. The disappearance of the decarburised band was due simply to the fact that the removal of metal by oxidation became greater than the rate at which carbon diffused through it.

The addition of CO to the neutral furnace atmosphere caused a slight decrease in the rate of scale formation with the plain carbon steels. Adding 4% of CO diminished the scaling of the low-carbon steel by roughly 10%, but this amount of CO had little effect in the presence of 0.20% of  $\text{SO}_2$ . Similar results were

obtained with the high-carbon steel. The presence of CO has therefore little practical value in minimising scaling losses, hence no advantages can be claimed for a furnace atmosphere obtained by incompletely burning the fuel. On the contrary, it may be stressed that such atmospheres almost invariably produce oxides which are difficult to remove from the metal either by shot-blasting or by pickling.

When a fuel is burned with excess air, the free oxygen in the resulting furnace atmosphere produces a much more severe attack on the steel. As the free oxygen content of the furnace atmosphere rose to 2% there was a rapid increase in oxidation, but beyond this value there was little further increase. This falling-off in the effectiveness of the oxygen additions was associated with the formation of a smooth skin of ferric oxide over the otherwise brightly crystalline surface of the scale, and the latter became completely covered with ferric-oxide when the free oxygen concentration in the atmosphere reached 2%.

With a furnace atmosphere containing 0.20% of  $\text{SO}_2$ , the addition of free oxygen produced an increase in scaling which reached a maximum at approximately 1% of oxygen. Additions of oxygen beyond this value tended to inhibit the accelerating influence of the sulphur dioxide, and with the low-carbon steel the rate of scale formation in an atmosphere containing 5% of oxygen was the same whether  $\text{SO}_2$  was present or not. The important influence of oxygen in furnace atmospheres containing  $\text{SO}_2$ , however, was to prevent the formation of iron sulphide in the scale and thus minimise intercrystalline penetration of the latter into the steel. When the oxygen content was increased to 5% no evidence of sulphide formation could be found in the scale.

It will be clear that in dealing with sulphur-containing fuels it is not merely necessary to use more air than is required for complete combustion, but sufficient to give more than 2% of oxygen in the furnace atmosphere, and from a consideration of oxide penetration it would be advisable to adjust combustion so as to give a furnace atmosphere containing 5% of oxygen.

#### Alloy Steels

**13% Manganese Steel.**—The presence of manganese in steel seems to have very little effect on either the rate of scale formation or the type of scale produced. In all the atmospheres it was found that the 13% manganese steel behaved similarly to the plain carbon steels. The results obtained in furnace atmospheres containing  $\text{SO}_2$  and/or oxygen were very near those for the carbon steel.

Attention is drawn to the maximum oxidation at 1% of oxygen for the furnace atmosphere containing sulphur. In this atmosphere the normal scale was covered by a dry powdery overgrowth. With higher oxygen content in the atmosphere this powdery overgrowth became less and with 5% of oxygen it finally disappeared, leaving the usual ferric-oxide-covered type of scale.

**5% Nickel Steel.**—In atmospheres containing no free oxygen or  $\text{SO}_2$  the 5% nickel steel scaled at approximately half the rate of a carbon steel. This difference between nickel and carbon steels was less when the furnace atmosphere contained oxygen or  $\text{SO}_2$ .

The nickel steel showed a higher degree of intercrystalline penetration of scale than the carbon steels.

After an exposure of 1½ hours to the neutral atmosphere containing 0.2% of SO<sub>2</sub>, the penetration of scale extended to a depth of approximately 0.002 in. This atmosphere was chosen because it represents the most harmful set of furnace conditions likely to be found in practice—i.e., those obtained by the incomplete combustion of crude town gas (600 grains of sulphur per 100 cub. ft.) or fuel oil containing 3% of sulphur. The need, therefore, for using excess air in the combustion of sulphur-containing fuels for heating nickel steels is evident. The structure of the scale formed on the 5% nickel steel differed from that on the carbon steel only at the scale-metal interface, where there was a dispersion of metal particles in the inner layer of scale which was less pronounced in scales formed on the carbon steel.

**3.5% Nickel, 0.75% Chromium Steel.**—This steel closely resembled the 5% nickel steel in its scaling characteristics in each of the furnace atmospheres. The rate of scale formation and the type of scale formed were almost the same for the two steels. There was, however, less intercrystalline penetration of the scale into the metal with the nickel-chromium steel. There was also a finer dispersion of metal particles in the inner layer of scale.

**4% Silicon Steel.**—In the absence of both free oxygen and SO<sub>2</sub>, the 4% silicon steel had a comparatively low rate of oxidation—i.e., approximately one-fifth of the oxidation rate of a plain carbon steel. When the furnace atmospheres contained free oxygen or SO<sub>2</sub>, however, this superior resistance of the 4% silicon steel vanished and the rate of scale formation became greater than with the carbon steels. The reason for this behaviour was revealed by the structure of the scale formed.

In the absence of both free oxygen and SO<sub>2</sub>—i.e., neutral and reducing furnace atmospheres, the scale consisted of a very thin layer of iron oxide with an inner layer of silica-rich material. The degree of resistance to oxidation possessed by this steel in such atmospheres was undoubtedly due to a low rate of diffusion of both iron and oxygen in this silica-rich layer.

When free oxygen was present in the atmosphere the inner scale layer contained another phase, which was identified as a eutectic of iron oxide and fayalite. A specimen of this eutectic was prepared by melting together 15% of SiO<sub>2</sub> and 85% of FeO, and the resulting structure was found to be identical with the eutectic formed in the inner scale layer of the 4% silicon steel. The equilibrium diagram of Bowen and Schairer gives the melting point of the eutectic as 1,170° C., and its presence in the scale formed on the 4% silicon steel at 1,150° C. can be accounted for only by assuming the presence of additional components, such as iron, etc., which would lower the melting-point. The greatly increased rate of scaling in the oxidising atmosphere was evidently due to the presence of this liquid phase in the scale, since only negligible traces of fayalite could be found in the scales formed when the furnace atmospheres contained no free oxygen, and under these conditions much less scaling occurred.

This liquid phase at the scale-metal interface was not accompanied by intercrystalline penetration of scale into the metal as was the case with the steels previously discussed. The absence of this penetration with the silicon steel is important, especially as this class of steel is fabricated in sheet form.

A further characteristic of this steel was the extensive decarburisation which accompanied scaling. A carbon-free zone 0.08 in. in depth was found after 1½ hours at 1,150° C. in a highly oxidising atmosphere—i.e., 75% nitrogen, 10% carbon dioxide, 10% water vapour, 5% oxygen. Furnace atmospheres containing SO<sub>2</sub> were particularly reactive to the 4% silicon steel at this temperature. The attack increased rapidly with the smallest addition of SO<sub>2</sub> to the neutral atmosphere, and 0.07% of SO<sub>2</sub> produced a type of disrupted scale similar to that formed on a carbon steel in the presence of 0.20% of SO<sub>2</sub>.

The appearance of a specimen scaled in the neutral atmosphere containing 0.20% of SO<sub>2</sub> indicated that incipient fusion had occurred. The addition of CO to this atmosphere produced a more fluid scale, which dripped from the specimen; there was also a further increase in the scaling rate. With the present apparatus it was difficult to measure accurately the rate of formation of scale when it was molten and no values are given for this particular atmosphere.

The behaviour of the 4% silicon steel in furnace atmospheres containing both SO<sub>2</sub> and free oxygen was governed by the amount of oxygen actually present. Small additions of oxygen accelerated the rate of scaling, but above 3% the effect was negligible. Increasing the oxygen content, however, produced a more compact type of scale.

The microstructure of the scale formed in the neutral atmosphere to which SO<sub>2</sub> had been added consisted chiefly of massive iron oxide with an inner layer in which two separate eutectics were visible—i.e., oxide-sulphide and oxide-fayalite. A scale containing two liquid products at the temperature of formation explains the increase in attack with the first additions of oxygen. The subsequent fall in the oxidation curve as the oxygen in the atmosphere is increased to 5% is due to a decrease in the iron-sulphide content of the scale.

The clearly defined decarburised zone found with the 4% silicon steel in sulphur-free atmospheres also occurred when sulphur was present, but there was no evidence of intercrystalline penetration of scale into the metal; this is remarkable in view of the fact that there were two liquid phases at the scale-metal interface.

**3% Silicon, 9% Chromium Steel.**—In an earlier paper<sup>2</sup> it was stated that at 1,000° C. this steel did not readily oxidise except in high-sulphur atmospheres; a protective oxide skin formed on the steel, which became unstable only when the SO<sub>2</sub> content of the furnace atmosphere approached 0.1%. At 1,150° C. there was no evidence of this protective skin, and scaling was consequently more intense, although in sulphur-free atmospheres the rate of oxidation was much lower than with the nickel, manganese or carbon steels. Unlike that on the 4% silicon steel, the scale formed on the silicon-chromium steel did not show signs of incipient fusion in the high-sulphur atmospheres, and, as the silicon content of both steels was of the same order, this higher melting point of the scale may be attributed to the presence of chromium oxide. Decarburisation was less severe, but the scale-metal interface was not as smooth as with the silicon steel.

**Chromium, Chromium-Nickel and Chromium-Nickel-Tungsten Steels.**—The results obtained with a range of

<sup>2</sup> A. Preece, G. T. Richardson, and J. W. Cobb. First Report of the Alloy Steels Research Committee, Section XI, p. 215, *The Iron and Steel Institute*, 1936, Special Report No. 14.

chromium and chromium-nickel steels showed that the scaling characteristics are intimately bound up with the stability of the chromium-rich protective oxide film which forms on the surface of the steel immediately it is exposed to a furnace atmosphere. These films are less stable in furnace atmospheres containing  $\text{SO}_2$ , but free oxygen in the atmosphere has the opposite effect. At  $1,150^\circ\text{C}$ . the 12% chromium steel had an appreciable rate of scale formation, especially in atmospheres containing  $\text{SO}_2$ , where scaling was of the same order as with carbon steels.

In sulphur-free atmospheres at  $1,000^\circ\text{C}$ . oxidation of this steel was limited to the formation of a green film. This film, however, had no stability at  $1,150^\circ\text{C}$ . and normal scale formation occurred. In sulphur-free atmospheres, therefore, there is a marked difference in the scaling rate at  $1,000^\circ$  and at  $1,150^\circ\text{C}$ . The scale formed at  $1,150^\circ\text{C}$ . consisted of an outer layer of iron oxide with a complex inner layer of fine mixed oxides and metal particles. The scale-metal interface was somewhat irregular and would tend to produce an anchoring effect on the scale, making it adherent.

When  $\text{SO}_2$  was present the scaling rate was greatly increased, but in all cases only slight traces of iron sulphide could be detected in the scale and consequently deep intergranular penetration did not occur.

Increasing the chromium content of the steel to 18% does not appear to produce any appreciable difference in scaling properties in the neutral and reducing furnace atmospheres, even when they contain  $\text{SO}_2$ . It seems that it is only in furnace atmospheres containing free oxygen that the increase in chromium content has any marked influence, and this is revealed by a tendency to strengthen the protective film. But, even so, the stability is uncertain.

The scaling properties of the 18% chromium, 8% nickel steel were also governed by the breakdown of the protective film. The addition of the nickel resulted in a lower rate of scale formation, but film breakdown seemed to be as uncertain as with the 18% chromium, 2½% nickel steel. With both these steels, when scaling did occur the structure of the scale formed was similar to that obtained with the 12% chromium steel.

This irregular type of scaling is difficult to understand and a number of experiments were made to ascertain the factors which govern the breakdown of the protective film. The results were only of a negative character and are summarised as follows:—

- (1) The degree of surface finish of the steel was of little importance, but the method of grinding and polishing did seem to influence the formation of a more stable film. Vigorous grinding with appreciable heating of the specimen was more likely to give a surface which remained free from scale than careful polishing intended to avoid undue heating.
- (2) Preheating in air to  $600^\circ$  and  $1,000^\circ\text{C}$ . and also in the neutral atmosphere to  $1,000^\circ\text{C}$ . so as to form complete films gave only inconclusive results.
- (3) Heating the specimen slowly in the furnace atmosphere or placing the cold specimen into the furnace at  $1,150^\circ\text{C}$ . with the atmosphere flowing through it gave no reliable information.
- (4) An increase in the gas velocity over the surface of the specimen was without effect, but, on the other hand, a reduction in the gas velocity tended to secure more complete scaling.

(5) The longer the time at the scaling temperature, the more likely was the specimen to be completely covered with scale, but this scale layer was seldom of uniform thickness, indicating that failure of the film had occurred at various points on the surface of the specimen at different stages during the exposure to the furnace atmosphere.

(6) Additions of up to 5% of hydrogen to the neutral atmosphere seemed to have no effect on the stability of the film.

(7) Giving the specimen a high electrical potential both positive and negative in turn, and also maintaining a high-voltage discharge through the furnace atmosphere were all without effect on the stability of the film.

The above results, whilst inconclusive, would suggest that this uncertainty in the stability of the protective film may be associated with a condition of the specimen rather than with the furnace atmosphere.

In experimenting with more highly alloyed steels, such as a 20% chromium, 7% nickel, 4% tungsten, a 25% chromium, 17% nickel, and a 30% chromium steel, it became clear that an increase in the chromium and nickel content resulted in a more stable protective film.

**8% Aluminium Steel.**—In atmospheres free from  $\text{SO}_2$  and oxygen, oxidation was confined to the formation of a thin film which underwent very restricted breakdown at points on the surface to give small black crystals of scale. Additions of oxygen to the sulphur-free furnace atmosphere produced a greater number of isolated patches of scale.

The scale formed in sulphur-containing atmospheres consisted of three zones:—

- (1) An outer layer of massive iron oxide.
- (2) A complex inner layer.
- (3) A modified surface zone in the metal beneath the scale.

The complex inner layer consisted of a ground-mass of iron oxide in which well-defined crystals of alumina and minute grains of metal occurred. The modified metal surface contained filaments of scale which penetrated to a depth of approximately 0.015 in.

It may be mentioned that among attempts to produce by some pretreatment a stabilised alumina-rich film which would resist attack by furnace atmospheres at  $1,150^\circ\text{C}$ ., the M.B.V.† process was tried, but was not successful.

THE Minister of Supply has made a new Order which increases the maximum price of Admiralty gunmetal scrap of the quality commonly known as "88-10-2" from £74 10s. per ton, ex works, to £77 per ton, ex works. The maximum price of £74 10s. per ton had been in force since December, 1942. The increase maintains the relation between the maximum price of the scrap and the value of the contained metals, and is consequent on the recent increase in the price of tin. All inquiries should be addressed to the Non-Ferrous Metals Control, Grand Hotel, Rugby.

Copies of the Order, the Control of Non-Ferrous Metals (No. 14) (Copper, Lead and Zinc) Order, 1944, which came into force on March 20, 1944, may be obtained from H.M. Stationery Office, York House, Kingsway, W.C. 2, or through any bookseller, price 1d.

† Boiling in a solution of chromic acid.



## Proposed Memorial Lecture to the Late Dr. W. H. Hatfield, F.R.S.

THE many friends and colleagues of the late Dr. W. H. Hatfield, F.R.S., will no doubt be pleased to learn of a proposal to establish a Memorial to his great services to metallurgical science and to his outstanding achievement in promoting co-operative research within the iron and steel industry.

This Memorial should, it is proposed, take the form of an annual lecture, to be delivered under the auspices of the University of Sheffield, in association with the Iron and Steel Institute. In order that scientists of the highest distinction may be obtained as lecturers, irrespective of nationality, it is essential that the endowment should be sufficient; accordingly it is proposed to aim at establishing a capital fund of not less than £5,000. The Lectureship will be administered in accordance with the terms of a Trust Deed, and the University of Sheffield has agreed to act as Trustee. The lecture will be named "The Hatfield Memorial Lecture." Under the Trust Deed the University will determine the place where it shall be delivered on the recommendation of the Lecture Committee. Contributions to this fund have already been promised; subscriptions should be sent to:—K. Headlam-Morley, Esq., Secretary, the Iron and Steel Institute, 4, Grosvenor Gardens, London, S.W. 1, who has consented to act as honorary treasurer during the collection of the Fund. Cheques should be made payable to "The Hatfield Memorial Lecture Fund."

## Germany's Efforts to Meet Its Shortage in Industrial Diamonds

THE most important use to which Germany puts industrial diamonds is the truing of grinding wheels, and it is in this process that shortage causes most inconvenience. That the shortage of industrial diamonds is making inroads into the German technical system is emphasised by the number of articles published recently in the German technical press, a review of which has been prepared by Mr. P. Grodzinski,\* of Research Department of Diamond Trading Co., Ltd., London, E.C. 1. These German accounts show clearly that the diamond as a tool, wear-resisting and abrasive material cannot be excluded from modern industry without sacrifices in accuracy, time and labour costs.

This review of these German accounts of the extent to which diamond tools and diamond powder may be replaced by other materials in modern industry, is of considerable value to engineers in this country, but the author considers it desirable to acquaint readers with some of the problems encountered when considering possible substitutes.

It is stated that in every undertaking and industry there is an obvious desire to avoid the use of the diamond, and, from personal experience, the author knows that thousands of pounds have been spent by many industries to find adequate substitutes for the diamond. It is, of course, emphasised that, for many reasons, the diamond should only be used when it is suitable or essential. Actually, diamond experts are more concerned about the injudicious use of diamonds in fields where suitable substitute materials are known. For instance, diamond tool manufacturers are producing truing tools with truing wheels and glass cutters equipped

with rollers, for applications where such tools are considered more suitable, and they are in fact recommending sintered carbide tools where these will give better all-round results.

The relatively high initial cost of the diamond tool is a point for consideration, but it is generally realised that it is the all-round cost, rather than the initial cost, which is of greatest importance to industry, and when proper account is taken of the speed of operation, the quality of finish, and the small amount of maintenance and control work involved, it will be appreciated that the diamond has proved its usefulness in modern mass production.

The various tests and investigations recorded in this review demonstrate the efforts of the German machine industry to avoid, as far as possible, the use of a raw material of which they have been in short supply for at least two years. But it also shows very clearly that in all really important cases diamond tools and instruments equipped with diamonds are practically irreplaceable and careful study will enable the engineer to determine where diamonds are most usefully applied. Certain technical advances, made during the war period, in the German machine and tool industry, are noted.

## Correspondence—continued from page 294

The Editor, METALLURGIA.

Dear Sir,

I thank you for your letter of the 12th inst., enclosing a copy of Mr. Pameley-Evans' reply to my criticism. I do not think the first paragraph calls for any further comment.

With regard to emissivities I would point out that since the furnace control is operated from the load temperature, the controller is affected, not by the mechanism of heat transfer from radiants to load, but only by the effective value of that transfer at one point in the load.

If transfer were achieved by greater temperature differences and smaller rates per degree difference, the sensitivity of the furnace would be impaired, due to the time lag occasioned by the greater variation in the heat content of the radiants themselves—i.e., the "heat inertia" of the furnace would be increased.

Under these conditions also, any irregularities of contour of the load, projections, etc., which always respond quicker to temperature changes of the radiants, would result in a greater variation of temperature within the load itself.

For these reasons—namely, possible overshoot and local overheating—I stressed that the temperature of the radiants must be reduced to as near as possible the required load temperature as the load reaches that temperature, and therefore I conclude that the highest possible emissivity is desirable at all times.

Incidentally, do emissivities approach 100% when the load reaches temperature? Emissivity is a basic physical property, and whilst there is some increase with absolute temperature, I can find no grounds for supposing it is affected by the relative temperature of the surroundings.—Yours faithfully,

E. J. MARTIN,

A.C.G.I., B.Sc., M.Inst.F., A.M.I.Mech.E.

Templewood Engineering Co., Ltd.,

Slough,

April 17, 1944.

\* *Ind. Diamond Review*, vol. 4, 1944, pp. 4-6.

# Non-Ferrous Alloys for War Purposes

## A Review of Recent Schedules and Specifications

*Since we reviewed the war emergency specifications for non-ferrous alloys in our September, 1943, issue, some new specifications have been issued and additions made to Service Schedule, B.S./S.T.A. 7. These are discussed in the present review.*

**S**INCE the beginning of the war, in order to conserve the supplies of virgin metals available and also to meet the increased demands for non-ferrous metals and alloys, many war emergency specifications have been issued with regard to such materials. Consideration has also been given to the bearing metals in use in order to conserve available supplies of tin. The work of preparing new specifications has been carried out by the Non-Ferrous Metallurgy Industry Committee of the British Standards Institution, by the Non-Ferrous Metals Control and by certain Service Departments, and a review of the work done up to the end of 1942 was given in METALLURGIA for September, 1943. Since then one or two new specifications have been issued, and additions have been made to Service Schedule B.S./S.T.A. 7, dealing with the rationalisation of non-ferrous metals and alloys for armaments and general engineering purposes. Such specifications as have been issued and such additions as have been made for 1943 are now considered.

### New B.S. Specifications

Two new war emergency specifications are for lead alloy pipes and for secondary zinc alloy for die-casting, and two new B.S. specifications are for the gas welding of aluminium and certain aluminium alloys and for test-pieces for the production control of aluminium alloy spot welds.

The specification for lead alloy pipes, B.S. 1085 : 1943, was prepared at the joint request of the Ministry of Works and Planning and the Non-Ferrous Metals Control, Ministry of Supply, with a view to ensuring the maximum economy in the use of lead as the quantity of lead now available for all purposes is extremely limited. The composition of the metal, 0.003 to 0.005% silver, 0.003 to 0.005% copper and impurities, not exceeding 0.005, 0.001, 0.002, and 0.01% of antimony, zinc, tin and bismuth respectively, differs from that required under B.S. 602. It has been found that small percentages of alloying materials (copper and silver) have the effect of increasing the resistance of the pipes to creep due to steadily maintained internal pressure, as the alloy is capable of withstanding higher stresses than those which can safely be imposed upon commercial lead. This increase in resistance is such that wall thicknesses of pipes and consequently weights can be reduced very considerably. Solder joints can be made with the new alloy as easily as with ordinary lead pipe, and it is just as easy to work and handle.

The B.S. 1141 : 1943 war emergency specification for secondary zinc alloy for die-casting has been prepared to make use of redundant zinc alloy castings A and B, conforming to B.S. 1004 : 1942. The ingot alloy metal is specified to contain 3.9 to 4.3% aluminium, not more than 1.0% copper, 0.03 to 0.06% magnesium, and

0.10, 0.007, 0.005, 0.005 maximum each of iron, lead, cadmium and tin. A large tolerance on copper has been allowed, and the limits of other impurities have been raised above the low limits of B.S. 1004. On account of this tolerance on the copper content, neither the dimensional stability and the retention of strength at elevated temperatures of alloy A, nor the good castability and high tensile strength of alloy B can be consistently expected. The initial physical properties of the alloy will vary between those of alloy A and alloy B, and it is urged that the applications of this alloy should be confined to uses where maintenance of physical properties and dimensional stability are not of primary consequence.

The gas welding of aluminium and aluminium alloys is the subject of B.S. 1126 : 1943. This specification was prepared at the request of the Welding Industry Committee to afford guidance as to the standard which should be reached by welding joints in aluminium and certain aluminium alloys. The specification refers to the welding of aluminium and two types of aluminium-rich alloys, the 1.25% manganese alloy and the 10 to 13% silicon alloy, by the atomic hydrogen process or by an oxy-gas process, in which the gas used may be acetylene, hydrogen, propane, butane or coal gas. It covers material in the form of sheet castings, tubes, bars and sections. An appendix includes details of the chemical composition, condition and mechanical properties of the aluminium and all the alloys quoted which are to appropriate British Standards. The quality of filler rod, the flux (a suggested composition is given), type of joint, mechanical tests, and visual and radiographic inspection are also dealt with.

Specification B.S. 1138 : 1943 has been prepared to standardise for production control test-pieces for testing in shear spot welds between light alloy sheets or strips of aluminium base alloys, so that a reliable indication of the quality of the weld may be obtained. It does not include the shear testing of welds in commercial aluminium. Designs are based on a minimum strength per spot weld, and while any serious surface defect present may be detected by visual examination, the strength and consistency of spot welds must be checked by control tests made at appropriate intervals and under precisely the same operational conditions as the production welds. As the strength of spot welds is also affected within limits by the proximity of other welds, welds made singly or the first weld of a series do not give representative values, and further, there are normal variations between welds made under the same conditions. Misalignment of welds relative to the line of loading may also occur in production control testing, even after taking reasonable precautions in preparation and testing of specimens. The use of the two-spot specimen, whose preparation is described, reduces errors due to these causes. Welding procedure, testing

procedure and minimum strength requirements are also specified.

### Soft Solders

To meet wartime restrictions in supply of tin and to effect the maximum economy in the use of tin in soft solders without affecting production, an appendix to Services Schedule B.S./S.T.A. 7 was prepared at the request of the Ministry of Supply by the Solders Advisory Panel of the British Non-Ferrous Metals Research Association and issued in August, 1943.

Economy in tin in solders can be made in three ways: (a) By eliminating the use of solder, by the adaption of alternative methods of joining, such as welding, riveting or brazing; (b) by reduction in the amount of solder applied. This may be assisted in many cases by reducing the cross-section of the solder-stick or wire normally used. For the joining of lead pipes, wiped joints should be retained only in exceptional cases, and the more economical alternatives described in B.S. 219, Memorandum 3, should be used. Where these methods are not suitable, as in T joints, and joints in cable sheathing, the amount of solder should be reduced to the minimum by making the joint as short as possible; (c) by the use of economy solders—i.e., solders containing no tin or a smaller proportion of this metal than that which has been previously used. The L.S. series of economy soft solders is divided into four sub-series which are arranged in descending order of tin and form a separate series (L.S.) in the lead and alloy group in the Schedule B.S./S.T.A. 7. The composition of these solders are given in Table I.

TABLE I.—ECONOMY SOFT SOLDERS' COMPOSITIONS AND PROPERTIES.

Sub Series	No.	Description	Composition				Temp. at which Liquid °C.	Freezing Range °C.
			Sb.	Pb.	Ag.	Pb.		
A	LS/A1	Lead-silver-tin ...	5.0	—	1.4/1.5	R	300	—
	LS/A2	Lead-silver-tin ...	1.0	—	1.4/1.5	R	310	—
	LS/A3	Lead-silver ...	—	—	2.5	R	304	Nil
B	LS/B1	Lead-tin-antimony	12	8	—	R	232	9
	LS/B2	Lead-tin-antimony	5	4	—	R	282	42
C	LS/C1	Lead-tin-silver ...	45	—	1.41	R	218	40
	LS/C2	Lead-tin ...	38	1.7	1.22	R	227	49
	LS/C3	Antimony-silver ...	33	1.7	0.90	R	238	58
	LS/C4	Lead-tin-silver ...	30	—	0.63	R	251	73
	LS/C5	Lead-tin-antimony, Silver ...	28	1.5	0.61	R	249	69
	LS/C6	...	20	1.0	0.43	R	266	86
D	LS/D1	Lead-tin-antimony	44/45	2.3/2.7	—	R	215	30
	LS/D2	Lead-tin ...	41/42	0.4	—	R	230	47
	LS/D3	Lead-tin ...	39/40	2/2.4	—	R	227	42
	LS/D4	Lead-tin-antimony	29/30	1/1.7	—	R	248	63
	LS/D5	...	18/18.5	0.75/1.0	—	R	275	90
	LS/D6	...	...	...	...	R	...	...

R = Remainder.

Solders in sub-series A, lead-silver alloys with or without small quantities of tin are used successfully to replace high tin solders in certain machine and other soldering operations for both ferrous and non-ferrous alloys. These lead-base solders have considerably higher melting points than the majority of tin-lead solders, and hence higher temperatures are generally required in machine soldering and dipping baths, and in hand soldering larger and hotter irons are required, otherwise the use of these solders may result in increased production time. The use of an active flux is also sometimes necessary. These solders have notably high strength at elevated temperatures.

Lead-tin-antimony alloys, containing low tin and high antimony, sub-series B are suitable only for soldering

ferrous metals. They also require the use of a high soldering temperature and an active flux is sometimes necessary. Joints made in these alloys are inclined to be brittle, and therefore this type of solder should not be used for joints which may be subjected to shock in service.

Where the use of L.S./A or L.S./B solders has been found impracticable, a considerable tin economy results from the use of lead-tin and lead-tin-antimony alloys with small additions of silver, sub-series C. In cases where an L.S./C solder is used as a substitute for an L.S./D solder, experience has shown that such substitution can generally be made without serious modification in soldering technique, and where an L.S./D solder of the lowest tin content consistent with efficiency of operation is already being used, substitution of an L.S./C solder will generally enable some economy of tin to be made.

The lead-tin and lead-tin-antimony solders, grades C, D, G, M and N as specified in war emergency B.S. 249: 1942 form sub-series D and are used for various purposes. The use of L.S./D 4 for wiped joints should be restricted.

### Nickel and Its Alloys

Services Schedule B.S./S.T.A. 7 of non-ferrous metals and alloys was prepared from a statement of the joint requirements of the Services for non-ferrous metals and alloys for armaments and general engineering purposes. As the rationalisation of the whole field of non-ferrous metals and alloys required a survey of considerable magnitude, and in view of the time likely to be involved, only copper and its alloys, Group 1, were dealt with in the Schedule issued in 1942. During last year an additional section was added to the schedule dealing with nickel and its alloys, Group 2. This group covers compositions and properties of nickel, N series, and nickel-base alloys, N.S. and N.C. series, approved for service use, with details of relevant British and American Standard specifications and particulars of the uses of the respective types of material.

In the first series two grades of nickel are specified, refined nickel N1, and anodes N2. The former contains a minimum of 99% of nickel with small amounts of lead, carbon, sulphur, antimony and bismuth, and is used as ingot, shot or pellets suitable for remelting and alloying. Wrought metal conforming to this composition or to a higher grade of material, is used for specialised applications, such as radio valves, electric lamps, depth-sounding gear, sparking plugs, etc. Nickel for anodes contains 98.5% minimum of nickel with small amounts of iron, manganese, silicon, copper, zinc and carbon. It is used for alkaline accumulation parts, and for electroplating purposes, including the building up of worn or overmachined parts and surgical instruments, etc. Its use is restricted.

The nickel-copper-zinc (nickel silver) alloys, N.S. series, comprise four alloys containing approximately 43-48, 17-19, 14-16, and 9-11% nickel respectively. The first of these alloys in the form of sheet and strip, rods, tubes, wire and rivets is used for aircraft components, the second in the form of sheet and strip for telephone springs, etc., and the third and fourth alloys in the form of sheet and strip for instrument parts, surgical instruments, electrical apparatus and aircraft components. The composition and properties of these four alloys are given in Table II.

Nickel-copper alloys, N.C. series, are given in Table III, together with their condition and mechanical properties.



TABLE II.—NICKEL-COPPER-ZINC (NICKEL-SILVER) ALLOYS—N.S. SERIES.

No.	Description.	Composition.								Condition.	Proof Stress, Tons/sq. in.	Ult. Stress, Tons/sq. in.	Elong. %.	Brinell Hardness.
		Ni.	Fe.	Mn.	Cu.	Zn.	Pb.	S.	Others.					
NS. 1	(A) Sheet and strip	45/48	2.0	2.0	R	21/25	—	—	1.0	Annealed .....	15	35	25	—
	(B) Rod, tube, wire and rivets									Cold-worked .....	40	50	12	—
NS. 2	Sheet and strip, including spring	17/19	—	0.25	54/56	29/25	0.03	0.03	0.35	Annealed .....	—	—	—	80/105
										Cold-worked .....	—	—	—	130/200
NS. 3	Sheet and strip .....	14/16	0.2	0.5	60/65	R	0.04	—	0.3	Annealed .....	—	—	—	95 max.
										Cold-worked .....	—	—	—	125/180
NS. 4	Sheet and strip .....	9/11	0.25	0.3	60/65	R	0.04	—	0.3	Annealed .....	—	—	—	90 max.
										Cold-worked .....	—	—	—	115/170

R = Remainder.

Monel metal bar, rod, stampings and forgings are used for general engineering and aircraft applications where high strength and good resistance to corrosion are required. Material may be manufactured by hot-working operations when it is suitable for hot stampings, forgings, etc., while material manufactured by cold work may be specified either soft, intermediate or hard. The extra hard grade is available only for special applications, such as turbine blading. Monel tubes are used for chemical plant and aircraft tubing; Monel wire for filter gauze, springs, and welding electrodes for cast iron; Monel plate manufactured by hot working for heavy chemical plant; and Monel sheet and strip manufactured by cold working for aircraft components.

Normal Monel metal castings and 2.75% silicon Monel metal castings are used for pump impellers and chemical applications, the latter also being used for steam valve lids and seats. 3.75% silicon Monel metal castings have limited application. Hot rolled bar,

rod and forgings of "K" Monel metal used mainly in the heat-treated condition (aged 4 hours at 590° C. and slowly cooled) find application for large valve stems, propeller shafting and forgings, while cold-worked bar, rod, tube, turbine blading, wire and strip of the same alloy used mainly in heat-treated condition (aged 4 hours at 520°-560° C.) is used for non-magnetic aircraft parts, springs and turbine blading.

Copper-nickel alloys, N.C. 5 to N.C. 8, comprise 60/40 cupro-nickel strip and wire, 70/30 condenser tubes and ferrules, 80/20 strip for aircraft components and other limited applications, and 96/4 driving bands for heavy naval shells.

Nickel-chromium, nickel-iron and nickel-chromium-iron alloys are available for special applications where high electrical resistance, heat resistance, and magnetic properties are required. These have not been included in the Services schedule, however, owing to their variety and their availability principally as proprietary materials.

TABLE III.—NICKEL-COPPER ALLOYS—N.C. SERIES.

No.	Description.	Composition.										Condition.	Proof Stress, Tons/sq. in.	Ult. Stress, Tons/sq. in.	Elong. %.	Brinell Hardness
		Ni.	Fe.	Mn.	Al.	Si.	Cu.	Pb.	C.	S.	Other					
NC. 1	(A) Monel rod, bar, etc.	63/70	2.5	2.0	0.5	0.5	R	—	0.3	0.02	0.5	Hot-rolled .....	10	34	35	120/140
	(B) Monel rod, bar and turbine blading											Annealed .....	7	30	35	110/120
	(C) Monel tubes											Cold-worked .....	30	40	14	190/210
												Extra-hard .....	—	45	18	—
	(D) Monel wire											Annealed .....	—	29	20	—
												Cold-worked .....	—	40	10	—
	(E) Monel plate											Annealed .....	—	29	35	—
												Cold-worked .....	—	55	2	—
NC. 2	(F) Monel strip and sheet	63/68	3.0	0.5/1.5	—	0.25/1.2	R	—	0.1/0.35	0.06	0.5	Hot-rolled .....	—	34	35	120/140
	Annealed .....											7	30	39/35	100/110	
	Cold-worked .....											30	45	14	200/220	
NC. 3	Normal Monel castings ..	63/68	3.0	0.5/1.5	—	2.5/3	R	—	0.1/0.12	0.05	0.5	As cast .....	—	33	10	—
	(A) 2.75% Si Monel castings	63/68	3.0	0.5/1.5	—	2.5/3	R	—	0.1/0.12	0.05	0.5	As cast .....	—	33	10	—
	(B) 3.75% Si Monel castings	63/68	3.0	0.5/1.5	—	3.5/4	R	—	0.1/0.12	0.05	0.5	As cast .....	—	40/45	Nil	230/260
NC. 4	(A) "K" Monel metal rod and forgings	R	2.0	2.0	2/4	—	27/33	—	—	—	1.0	Hot-rolled .....	—	39	35	130/160
	(B) "K" Monel metal rod, tube, turbine blading, wire and strip											Hot-worked and heat-treated .....	—	60	30	250/280
												Cold-worked .....	—	—	—	200/220
	(B) "K" Monel metal rod, tube, turbine blading, wire and strip											Cold-worked and heat-treated .....	—	72	15	300/320
												Cold-worked and softened .....	—	—	—	120/150
												Cold-worked, softened and heat-treated ..	—	58	30	240/270
												Annealed .....	—	25	—	—
	NC. 5											60/40 strip and wire ...	40	0.5	1.0	—
NC. 6	70/30 condenser tubes ..	30	0.4/1	0.5/1.5	—	—	R	—	—	0.08	0.3	—	—	—	—	
NC. 7	80/20 strip .....	19/21	0.2	0.35	—	—	81/79	—	0.04	0.025	0.25	Annealed .....	—	20	33/38	—
NC. 8	96/4 driving bands .....	4.5	0.1	0.25	—	—	95/96	—	—	—	0.2	—	—	—	—	

# MICROCHEMISTRY

APPARATUS · METALLURGICAL APPLICATIONS · TECHNIQUE

APRIL, 1944

METALLURGIA

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**T**HE divergence of opinion regarding how much microchemistry it is advisable or desirable to teach to students of chemistry is only one aspect of a much larger issue—the teaching of up-to-date methods in general. Admittedly, there must be no undue economy in the instilling of the basic principles of chemistry, but it must not therefore follow that basic principles should, fetish-like, blind us to all else. Because the retort was once a stock piece of apparatus in chemical work, no one expects that every student should regard the retort as a fundamental part of his equipment when he blossoms forth as a qualified chemist. So it seems only reasonable to expect that if the theory of qualitative analysis can be adequately taught to a class using semi-micro methods, macro methods might well receive only a passing consideration. From all accounts that reach us through the literature of education from the United States of America, where more attention seems to be paid to the theory of the teaching of chemistry, semi-micro methods have proved their worth as a teaching medium. Other methods within the abilities of the average student might at least be taught as an alternative to the standard methods if not as a replacement. This raises difficulties, both obvious and less immediate. But surely, to the scientist, obstacles are an incentive, not a deterrent. We will advert to this subject again.

## Organic Reagents in Quantitative Metallurgical Micro-Analysis—Part I

By R. Belcher and C. E. Spooner

*The theory underlying the application of organic reagents to micro-metallurgical analysis is summarised. Particular attention is directed to compounds in which some of the principles of complex formation are indicated. A subsequent article will review some of the more recent practical methods by which these compounds have been utilised in the micro-determinations of metals.*

**Q**UANTITATIVE metallurgical analysis has been greatly enriched in recent years as a result of the research work which has been directed to a study of the compounds formed between metals and organic compounds. These compounds can be divided into two classes, the simpler class consisting of those compounds formed by the direct combination of a metal with an organic acid to give a normal salt, and the other class comprising those combinations which give rise to substances which have been termed complex compounds. Of these two classes, that dealing with the complex compounds has proved the most fruitful in providing methods of determination which possess high sensitivity, rapidity of operation, and specificity of action. They form the basis of spot tests which have revolutionised qualitative micro analysis, and are being applied to an increasing extent in absorptiometric methods of quantitative metallurgical micro analysis. The importance of this field is instanced by the number of relevant monographs now available, such as those by Prodinger,<sup>1</sup> Feigl,<sup>2</sup> Strafford<sup>3</sup> and Vaughan.<sup>4</sup> This article deals with

their application in metallurgical micro analysis, but before reviewing recent applications it is considered desirable to summarise the theory underlying the application of organic reagents to micro metallurgical analysis in general, which has been so efficiently exploited by Feigl and his co-workers.

Little need be said about the use of organic reagents which give normal salts with metals. The chief advantages of their use in quantitative analysis is that the precipitates obtained with them are easily freed from impurities and possess a very favourable conversion factor which makes them very suitable for micro-quantitative analysis. Anthranilic acid has received much attention, but its use is limited because it gives precipitates with so many ions. Its chief use lies in replacing some of the more conventional weighing forms, after separating the particular ion being determined by other means—for example, lead can be determined as anthranilate, instead of as sulphate or molybdate. In certain restricted types of metallurgical analysis it can be used when interfering elements may be absent or

<sup>1</sup> W. Prodinger, "Organic Reagents Used in Quantitative Organic Analysis," Elsevier Publishing Co., New York, 1940.

<sup>2</sup> F. Feigl, "Specific and Special Reactions," Elsevier Publishing Co., New York, 1940.

<sup>3</sup> N. Strafford, "The Detection and Determination of Small Amounts of Inorganic Substances by Colorimetric Methods," Inst. of Chemistry, 1933.

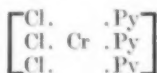
<sup>4</sup> R. J. Vaughan, "The Use of the Spekker Photo-Electric Absorptiometer in Metallurgical Analysis," Inst. of Chemistry, 1941 and 1942.

conditions chosen which prevent their interference, and one such method will be referred to later. Picrolinic acid is a more useful reagent, as it can be used in the presence of many other ions and is used for the micro determination of calcium, lead and thorium.

The theory underlying the formation of complex compounds is by no means complete at the present time, but the main outlines have been established for a number of years. The basis of this theory was first laid down by Werner in 1891, who proposed that certain atoms have a tendency to attach to themselves a definite number of other atoms or groups. This property is additional to the normal valency of the atom, and he called it the co-ordination number, each atom having a maximum co-ordination number, usually six or less often four, although it can also form co-ordinately unsaturated molecules in which this number is not reached. The explanation of this property which has since been made by the electronic theory of valency is that whereas in electrovalency an atom completes an octet of electrons in its outer electron shell by the transfer of an electron from one atom to another, thereby producing electrically charged ions, and in covalency the outer octet of electrons is completed for each of two atoms by the sharing of two electrons by these two atoms, each contributing one electron, in the co-ordinated complex compounds the valency group is made up to an octet of electrons, or for certain atoms is increased to 12 electrons, and both of the two electrons in the additional pairs are contributed by the same atom. Such a valency linkage is called a co-ordinate link, and differs from covalency only in that both of the two electrons shared by the two atoms so joined are contributed by one of the atoms.

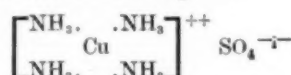
On the basis of Werner's Theory complex compounds are classified into three main types, which are called addition compounds, intercalation or penetration compounds and inner complex compounds. There are a few special compounds which fall outside this classification, but the vast majority of complex compounds, and especially those which are used in metallurgical analysis, fall into it.

In the addition compounds the co-ordination of further atoms or groups on to the central co-ordinating atom strengthens the valency bonds already present. Thus chromic chloride will form a complex compound with pyridine, wherein three pyridine molecules are co-ordinately linked to the chromium atom. In aqueous solution this complex compound is a non-electrolyte, a fact which is expressed by the co-ordination formula—

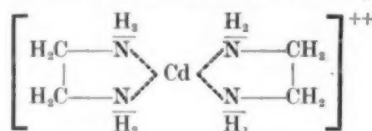


Consequently the co-ordination of the pyridine molecules on to the chromium atom so strengthens the bonds already existing between the chromium and chlorine atoms that they become stabilised and non-ionic. However, it is not a prerequisite property of addition compounds that they shall be non-ionic, for example, cobalt nitrate forms an addition compound with potassium nitrate—namely,  $(\text{Co}(\text{NO}_3)_6)\text{K}_3$ , and this is ionised in solution. It is called an addition compound because the bonds between the cobalt atom and the nitrate radicals originally present in cobalt nitrate are so strengthened in the addition compound that they are not broken when this compound ionises.

The term intercalation or penetration compound is derived from the fact that in these compounds the valency bonds originally present in the parent substance are weakened by the formation of a complex compound, and the entrance of the co-ordinated ligands, as they are called, can be regarded as entering between the radicals originally present. An example is the complex compound copper tetramine sulphate—



in which only the ammonia molecules are bound complexly to the copper ion, and the sulphate ion remains electronically bound. It is possible for ring systems to be formed in these penetration compounds and this usually occurs when ethylene diamine is the added ligand. Thus the cadmium ion forms the complex ion—



This is, however, still a penetration compound and not an inner complex compound, as will be explained in the next paragraph.

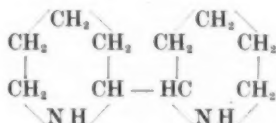
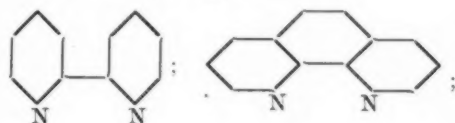
Inner complex compounds, which constitute the third type of complex compounds, always contain a ring system. This ring system in inner complex compounds is always formed by a metal replacing a hydrogen atom of an acidic group in a molecule and then forming a co-ordinate linkage with another part of the same molecule. Thus, in inner complex compounds, the co-ordinating atom is always bound by a salt-like covalency and a donated co-ordinate valency to the same ligand. The formation of this ring system depends upon several factors, including the nature of the metal atom, the position of the salt and complex-forming groups, and the structure of the remaining part of the added molecule.

The relative positions of the salt and complex-forming groups govern the formation of inner complex compounds because in ring formation a bending or straining of the valency linkages is liable to occur. These straining forces were explained by Baeyer's strain theory, which shows that five- and six-membered rings possess the least amount of strain. The co-ordinate linkage is the weakest type of valency bond, thus, while compounds are known containing rings with any number of atoms from 3 to 18, stable inner complex compounds are only to be expected when an atom can form part of a five- or six-membered ring. This limitation reduces the number of inner complex compounds which are purely inorganic, and inorganic complex compounds are mostly addition or intercalation compounds. Complexes formed by the co-ordination of organic compounds, on the other hand, because of their variety and the possibility of introducing acid groups as well as groups endowed with auxiliary valencies into the molecules of organic compounds, comprise the most prolific type of organic reagent, and the possibilities of research work in this direction have by no means been exhausted.

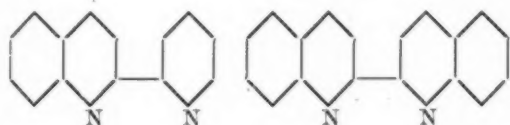
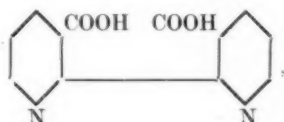
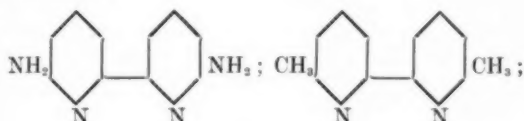
The nitrogen atom and, to a less extent, the oxygen atom, have the greatest tendency to donate a pair of electrons for the formation of a co-ordinate linkage,



thus most of the organic reagents used at the present time for the formation of these complex compounds contain a nitrogen atom in a suitable position for co-ordination. The structure of the remaining part of the molecule nevertheless has an effect on whether this co-ordinate linkage is formed by the nitrogen atom or not. Thus the three compounds—

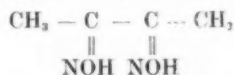


all form with ferrous salts intensely red complexes which are soluble in water and stable towards acids. On the other hand, the following compounds do not react with ferrous salts:—

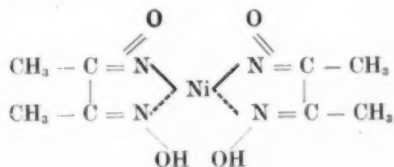


Thus the substitution of two  $\text{CH}_3$  groups, or two  $\text{COOH}$  groups, or other groups into the molecule can rob the nitrogen atom of its co-ordinating power.

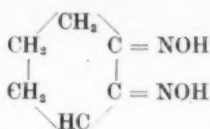
The complex compounds referred to in the preceding paragraph are penetration compounds, but the same influence is noticed in inner complex compounds. This is illustrated by the action of the dioxime group with nickel. Dimethyl glyoxime,



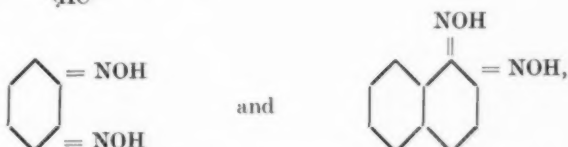
gives a red complex compound with nickel which is usually given the formula—




A similar compound is produced by *o*-cyclohexane dione dioxime,



but if the dioxime groups are associated with unsaturated aromatic rings as in



then the power to form inner complex compounds with nickel is lost.

The influence of the nature of the metal atom on the formation of inner complex compounds is illustrated by the fact that the copper salt of amino acetic acid is a typical inner complex compound, while the zinc and cadmium salts, on the basis of their conductivity in aqueous solution, cannot be inner complex compounds. Similarly, where a nitrogen atom is linked cyclically in the  $\alpha$ -position to a carboxyl group as in  $\alpha$ -piclic acid   $\text{COOH}$  and analogous compounds,

such compounds do not give inner complex compounds with copper, but always produce them with ferrous salts. This individuality shown by metals in their property of forming inner complex compounds is of great importance from the analytical standpoint, as it determines whether a reagent is specific—that is, characteristic for one metal only, or not.

Although there is still much empiricism attached to the investigation of new organic reagents, within certain limits it is possible to adopt a methodical line of investigation. Thus the dioxime grouping is considered specific for nickel, the  $>\text{C}(\text{OH}) - \text{C}(\text{NOH})$  group for copper, and the  $-\text{CO} - \text{CH}_2 - \text{CO}$  for thallium. However, unless the correct conditions are chosen, it is possible to get precipitates with other metals with all these reagents. Nevertheless, such a classification is of great importance in guiding the lines of further research work.

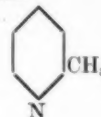
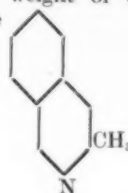
The reason inner complex compounds are of such importance in analytical chemistry is because the formation of a ring system stabilises the molecule. It also saturates the combining power of the metal atom and inhibits both a dissociation and an addition of water molecules, thereby inhibiting hydration and solubility in water due to the metal atom. The organic character of the reagent also comes into play and causes the compounds to be soluble in organic solvents and insoluble in water, and this greatly increases their sensitivity. The ring structures produced also cause the complex compounds to have characteristic colours, which is made the basis of spot-testing and absorptiometric analysis.

To increase the use of these compounds in analytical work several devices can be employed. The first of these to be dealt with has been termed masking—that is, when a reagent normally reacts with several metals and is said to be selective for these metals, it can be made specific for one metal by variation of the external conditions under which it is used. The external condition most easily varied is the pH value, and the adjustment of the acidity to an exact value will often make a reagent

specific for one metal. Another means of varying the external conditions is to remove the interfering material by the formation of a soluble complex substance prior to the addition of the reagent used for the specific determination. An example of this is the use of a  $\alpha$  dipyridyl or of a  $\beta$  phenanthroline, which, as already stated, give deep red complex ions with ferrous salts, to prevent the interference of iron in the precipitation of magnesium, beryllium, aluminium and titanium.

Other methods that are used to increase the use of these reagents is by varying the structure of the molecules containing the active groups. It has already been pointed out that the structure of the organic compound containing the active groups has an effect on whether a complex compound is formed or not. In a similar manner it will have an influence upon the sensitivity of a reaction, thus cyclohexanedione dioxime is twice as sensitive as dimethyl glyoxime in the detection of nickel in spite of the fact that cyclohexanedione dioxime is easily soluble in water and dimethyl glyoxime has to be used in alcoholic solution. Therefore with a knowledge, and the preservation, of the special action of certain groups it is possible, by introducing other groups or general preparative procedure, to so alter the molecule of the reagent that its analytical property is improved and adapted to the conditions required. There are two general principles which can be applied for this purpose, the first is that the sensitivity of a specific group in an organic reagent rises considerably with increasing

molecular weight of the reagent. Thus  $\alpha$ -naphthylquinaldine is 150 times as effective in the detection of bismuth as is picoline



The second general principle applicable for increasing the adaptability of a reagent for a particular procedure is most easily illustrated with reference to solubility in water. It is known that ethyl alcohol is completely miscible with water, but when the oxygen atom is replaced by a sulphur atom the resulting ethyl mercaptan is only very slightly soluble in water. Thus the replacement of a single atom can have a profound effect on solubility and greatly improve the sensitivity of a reagent.

This completes the brief review of the theoretical aspect of complex organic metal compounds in which some of the principles underlying complex formation have been indicated. For a more detailed treatment the texts by Feigl, Pfeiffer and Prodingers should be consulted. In the second part of this article we shall briefly review some of the more recent practical methods by which these compounds have been utilised in the micro determination of metals.

## Micro-Analysis of Fuels

WHILE the most prominent advantages of micro-analysis—i.e., saving of time and of materials—are not always so obvious in the analysis of fuels as in many other branches, occasions arise when micro-technique proves not only preferable, but, in fact, almost essential. This will often be so in research problems where, for example, only very small samples of various fractions are available.

To meet such demands, micro methods have therefore been devised, and typical applications to solid fuels have been summarised in two recent articles.<sup>1</sup> Some fuel methods have been suitable for adaptation to the micro scale without any pronounced alteration, while other conversions have demanded the devising of new procedures.

Attention is first directed to the increased necessity for care in sampling, requiring that all material to be sampled should pass BSS 120 mesh. As a result, moisture is lost in preparation of the material, and as-received moisture must first be determined on the macro scale. However, air-dried moisture can then be determined on the micro scale. A special apparatus built up from two small electric furnaces permits the latter operation and ash determination to be carried out on a single 5–10 mgm. sample. Dry nitrogen passed over the sample in a boat in the first furnace removes the moisture, which is estimated by loss in weight. The boat is then transferred to the second furnace and the fuel ashed carefully in an oxygen stream at 950° C., the weight of ash being then determined.

Volatile matter may be determined by a modification

of a macro method, using 3 mgm. instead of the 1 g. sample required by the older method. Oxygen-free nitrogen is passed over the sample, which is heated at 925° C., after all the air has been swept out of the furnace.

Carbon dioxide in mine dusts may be determined either directly or indirectly. In the former case the gas is liberated by acid and absorbed in baryta, which is then titrated. In the second procedure the ash is treated with excess standard acid, and the excess determined by titration with N/100 alkali.

Carbon and hydrogen in solid fuels may be determined either by the Pregl method or the Friedrich method, the latter, which employs a combustion tube containing a platinum contact, being the more convenient. Starting with a single 5 mgm. sample of mine dust, it is actually possible to determine moisture, ash, carbon and hydrogen, and carbon dioxide by the indirect method.

Kjeldahl or combustion methods may be applied for determining nitrogen, the precise method used depending on the nature of the fuel. Sulphur cannot be determined by any direct modification of the Pregl procedure because of the formation of stable sulphates in the ash. These sulphates may, however, be decomposed by burning the sample, covered with alumina, at 1,350° C. The gases from the combustion are then passed through 1% hydrogen peroxide, which retains the sulphur oxides as sulphuric acid and the chlorine as hydrochloric acid. Total acid is first determined, and then hydrochloric acid (by mercury oxy-cyanide), giving sulphur by a difference calculation.

1. Belcher and Spooner, *Iron and Coal Tr. Rev.*, 1944, **148**, 79, 134.

## Production of Iron Sponge at Söderfors by the Wiberg Method

By Einar Ameen

THE production of pig-iron from iron ore, for the subsequent production of malleable iron, is a somewhat roundabout method, and the problem of producing iron directly from the ore has, therefore, long been of great importance. The theoretical basis of a suitable process was laid down in 1918 by Professor Wiberg.

$C + CO_2 = 2CO$  being endothermic, heat must be supplied, and this is provided by the electrical energy. The remaining gas (one quarter) passes farther up the shaft where an air-intake causes it to be burnt, thus heating up the ore to  $900^{\circ}$ – $1,000^{\circ}$  C.

After some years' experimental work with small plants a furnace capable of

600-mm. dia. carbon electrode in the top. The upper electrode still caused occasional stoppages.

The installation, after further minor alterations, finally left the experimental stage in 1941.

Considering Fig. 2, which represented approximately the final form, the ore, or sinter, was led in at 1. The shaft was lined with fire-bricks, and had a wall thickness of about 900 mm. This was surrounded by a sheet-iron cover. Between this and the brick layer was an intermediate layer of "Sil-o-cell" heat insulating

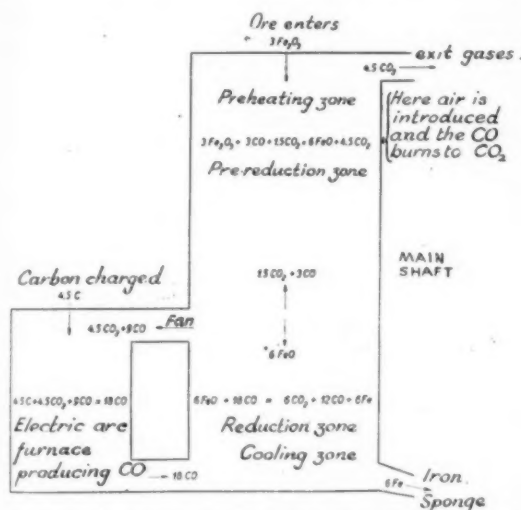


Fig. 1.—Diagram of Wiberg process.

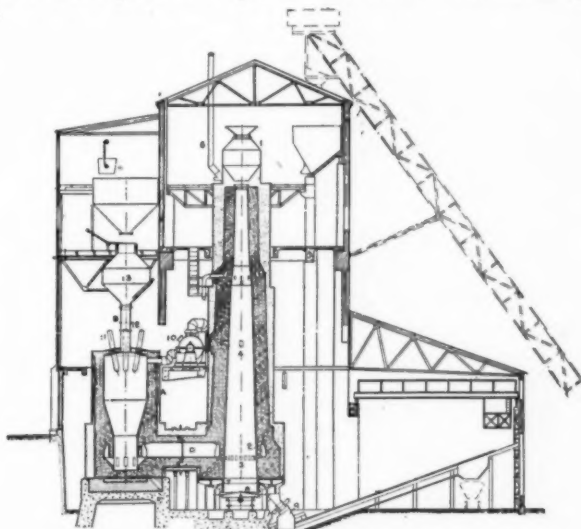


Fig. 2.—Iron sponge furnace at Söderfors.

In principle, the method, which is shown diagrammatically in Fig. 1, is as follows: The ore, either in sintered form, or in the form of uncrushed ore of high-iron content, is charged into the furnace, which works on the counter-current principle.

In the lower part of the shaft CO is passed in at a temperature of  $900^{\circ}$ – $1,000^{\circ}$  C. The gases passing up the shaft reduce the ore to iron, and the  $CO_2$  content of the gas rises to 25–30%, and equilibrium between  $FeO$ ,  $CO_2$  and  $CO$  being set up. Three-quarters of the gas is sucked out by means of fans into an electric arc gas producer, in which it is reduced to  $CO$ . The reaction to

producing 10,000 metric tons per year was laid down in Söderfors by the Stora Kopparbergs Bergslags Company in 1932. This is illustrated in Fig. 2. This plant could not be run continuously because the producer became gradually clogged with charcoal dust, and also the fan went out of action after a time. These difficulties were partially overcome by redesigning the producer, and the fan was made, first, from a cast 18% Cr, 20% Ni, 0.08% C heat-resistant steel; and finally, from a similar steel forged, and with titanium added. The form finally adopted for the producer was as shown in Fig. 3. This type had a lower electrode of the Söderberg type and a

powder. The various dimensions may be judged by the fact that the total height of the shaft from the ground to the top of the entrance chamber was 24 mm. The gas was led in at (2) through a ring conduit, and then through a number of narrow tuyeres in the shaft (3). The gases were led out through four exits (4). The air for the combustion in the upper part of the shaft entered through 12 tuyeres, and the used gases finally left by the chimney (6). The chimneys had valves to regulate the pressure in the shaft. The lowest part of the shaft was surrounded by circulating water (7). The sponge left the outlet (8) into the container (9). The gases from (4)



passed through the circulating fan (10), which could deal with 110 m<sup>3</sup>/mm. at 360 mm. pressure and 800° C., 2,950 r.p.m.

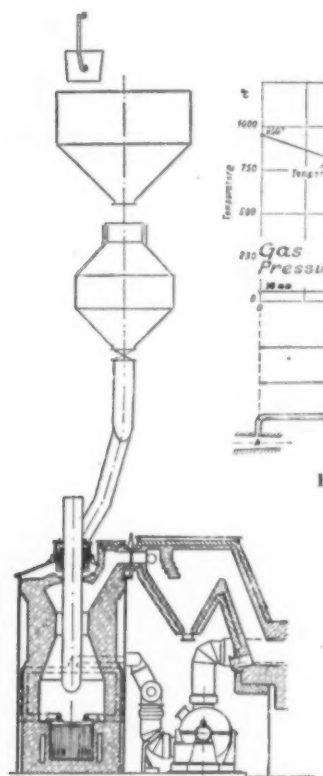


Fig. 3.—Single-phase producer.

The gas producer was lined in the same way as the shaft, the outer cover being, in this case, non-magnetic 18:8 Cr-Ni steel. The producer in the diagram had three Soderberg electrode pairs, 300 mm. dia., passing down through a collar, each electrode pair being coupled to its own single-phase transformer. The transformers were 400 kw. at 55-90 volts. The carbon was fed in through (12) from the carbon container (13), of 14 m.<sup>3</sup> capacity. The dust and ash had to be shovelled out at the bottom.

As regards the practical running of the furnaces, the producers are started up some time before use to warm up the plant, and the shaft is then filled with good, porous sinter. By regulating the voltage of the transformers the producer action is regulated and, thereby, the temperature of the gases to the shaft. This is between 950°-1,000° C. Above 1,000° C. there is risk of coagulations in the shaft, and below 950° C. there is a reduction in speed of working.

Fig. 4 gives a summary of the temperatures and pressures in various portions of the plant. The gases leaving the shaft at A must be cooled to 650° C. to go through the blower, which will not stand a high temperature. In the lower part of the shaft

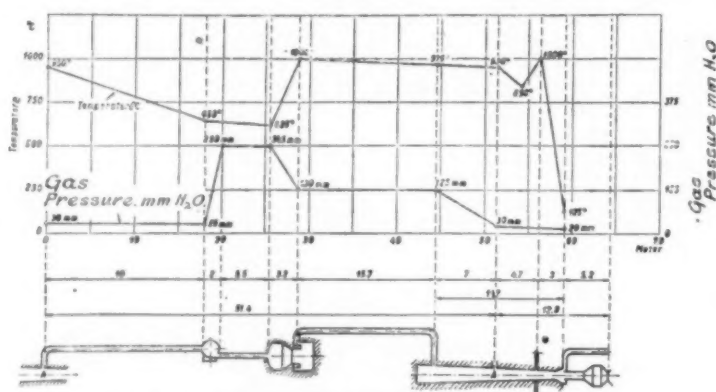


Fig. 4.—Temperature and pressure conditions in the iron sponge installation.

the reaction  $\text{FeO} + \text{CO} = \text{CO}_2 + \text{Fe}$  is exothermic, and the heat loss is small, so that the temperature remains high. Above A the reaction  $\text{Fe}_3\text{O}_4 + \text{CO} = 3\text{FeO} + \text{CO}_2$  is endothermic, and the temperature sinks to 850° C. In the higher zone, where the gases are burnt, the temperature rises to 1,000° C., and above this the ore entering the shaft cools the temperature to 100° C. The gas entering the producer has a  $\text{CO}_2$  content of about 30%, while that leaving it has only 2%, which indicates a high efficiency. The following table indicates the consumption and output for the period February 16th to 20th, 1943:—

Production	.....	22.5 metric ton Sponge/24 hours
Per metric ton Sponge:		Electrical energy = 750 kwh.
Charcoal	.....	= 175.7 kg.
Electrodes (Soderberg)	.....	= 3.05 kg.
Sinter: Fe	.....	= 50.52%
Calorimetric value of charcoal		= 6,641 k. cal./kg.
		{ Density, 17.5 kg./hl.

With a given size of furnace output is dependent on (a) temperature and composition of ingoing gases, (b) speed of gas circulation, (c) quality of the ore. The correct composition of gas is easily achieved, and its temperature is so closely defined within practical limits that not much can be done here. Increase in the speed of circulation increases output. Above a certain limit, however, the amount of  $\text{CO}_2$  in the gases entering the producer is reduced, since the ore is not reduced sufficiently rapidly for the  $\text{CO}_2$  to be increased to the required theoretical value of 30%, and the electricity and charcoal consumption per ton reduced iron automatically increases. The

suitability of the ore can be increased by pretreatment.

The possibility of using fuels other than charcoal was considered; wood was incorporated with the charcoal up to 30%. Above this its use was impracticable on account of moisture. Coke up to 40% was tried, and, contrary to expectation, was found to reduce the output of  $\text{CO}_2$ . Its use, however, required the insertion of a filter to remove the sulphur in the gases.

In the discussion Professor Wiberg explained that the process was designed in the first place to obtain maximum efficiency of energy consumption, and the question of whether iron sponge or cast iron was produced was of secondary importance. The same principle can be used for pre-reduction of ore in the electrical cast-iron production plant, whereby the ore is only pre-reduced to about 20-60%. The gas from the melting furnace is used in the pre-reduction shaft.

## Brazilian Iron Ore Mine

A DEPOSIT of 15,000,000,000 tons of high-grade iron ore near Itabira, Brazil, will be developed in 1944 to supply ore to the United States and Great Britain. Power will be transmitted at 69 kv. from a hydro-electric plant at Bello Horizonte to an outdoor sub-station, and a branch will be run to a similar outdoor sub-station. Each 2,000 kva. unit sub-station will step down to 2,400 volts for supply to drives for compressors, crushers, conveyors, and a pole-line feeder to the first place to be mined.

The ore will be mined in benches, drilled and blasted, and loaded into Diesel trucks by 4-yd. (3.65 m.) electric shovels. After primary crushing at the north end, six tandem, downhill, 125 h.p. conveyors will carry the ore to the secondary crushers, a mile (1.6 km.) away to the south. The ore will then be stacked, after which it will be reclaimed by tunnel and cross conveyors which load railroad cars for shipment to the sea-coast, 350 miles (560 km.) away.

From G.E. Review, January 1, 1944.

## Electrochemical Removal of Broken Tools

By J. L. Bleiweis and A. J. Fusco

**T**HE problem of salvaging and utilising all materials, especially in time of war, is an important one for any industrial establishment. Many castings in industry have to be rejected because various industrial tools, such as drills, reamers, taps, etc., have broken off in these castings in such a manner as to defy removal without seriously injuring the castings beyond the point of utility. In order to cope with this serious problem an electrolytic process has been developed whereby broken steel tools can be removed from aluminium and its alloys, and in the course of the development of this process the removal of broken tools from many other metals was also developed.

The process is based on the principle that the solution of metals in various electrolytes is enhanced if the metal is made the anode in an electrolytic process. For this application, however, it is necessary that the broken tool should be dissolved selectively without solution of any portion of the part to be salvaged. When applied to the combination of steel in aluminium, difficulty arises from the fact that aluminium is above iron in the electrochemical series and, therefore, more active. This complicates the problem, because optimum removal of broken steel tools will be effected only if little or no aluminium will be removed. Fortunately, however, aluminium under certain conditions will build up upon itself a protective oxide coating which, if it is non-porous and insoluble, will completely protect the aluminium from further attack.

The best solution for the removal of steel parts from aluminium castings was found to be a saturated solution of ammonium sulphate (750 grms. per litre). In many instances parts may be immersed in a tank as the anode in an electrical circuit, with ammonium sulphate as the electrolyte, and by electrolysis the broken steel tools may be removed simply and with no detrimental effect to the aluminium. This batch process is only applicable, however, when the part to be salvaged contains no metallic insets other than the part to be removed. Where such insets are present a special electrolytic apparatus was designed for the purpose of localising the electrolytic action

over the area of the broken tool to be removed.

Following the development of an apparatus on a laboratory scale, a commercial set-up was devised. This apparatus consists essentially for a hard rubber tube, the "Driller," with a length of hollow aluminium or Monel-metal tubing, which acts both as a cathode for the electrolytic process and as a conduit for recirculation of the electrolyte fitting through it. The top of the aluminium tube is connected to a suction manifold, and suction is obtained by means of a Monel-metal suction pump, which assures automatic recirculation of the electrolyte. The bottom of the aluminium cathode tube is fitted with a small rubber or acid-impervious tip, which has cut-outs at its lowest end to allow free solution flow and to prevent the cathode tube from contacting the casting at any time and causing short-circuiting. The voltage usually used varies from 24 to 50 volts.

In operation, the centre tube is adjusted so that the acid-impervious tip rests on the broken steel piece. The electrolyte is then allowed to flow into the "driller" from the solution supply vessel at the rate which gives maximum current. Recirculation is effected and leakage prevented by the suction built up by the pump. As the electrolytic tool removal proceeds, the cathode tube moves down into the hole so that the distance between the anode and cathode remains constant, and the current remains substantially constant also. When the ammeter registers zero, the removal of the steel tool is complete, and the hole occupied by it is washed out with water and 1:1 phosphoric acid.

The electrolytic removal of broken tools from magnesium is accomplished with the same apparatus as that described for aluminium, with modifications of materials only. The electrolyte is mainly 48 to 52% hydrofluoric acid with additions of inhibitors such as isopropyl alcohol, other alcohols, or organic compounds which will retard corrosion of the magnesium, and will not inhibit solution of the broken tool. The process can also be adapted by the use of suitable electrolytes for the removal of brass or bronze studs from aluminium; steel tools and studs from copper and copper-base alloys; steel tools or

studs, brass or bronze studs from Monel metal; and steel tools or studs, brass or bronze studs from stainless or corrosion-resistant steel.

The straight chemical or immersion process of removing broken tools from various metals has the advantage of being able to handle larger quantities of parts at one time, requires no equipment other than an immersion tank and possibly a temperature-control device, and features simplicity of operation with very little supervision or maintenance. The immersion method, however, has certain disadvantages which are inherent in the process, such as deterioration of certain finishes, effecting slight surface etching in some cases, and being inapplicable in cases where immersion will remove metal portions which should not be removed.

Removal of broken tools by chemical and electrolytic methods has certain advantages over mechanical methods. Threaded parts may be removed as easily as unthreaded parts, and hardened steel tools are removed as easily as softer studs. Tightly wedged broken tools present no difficulty and no surface-marring, due to chemical gouging, occurs at any time.

## Production of Low-Sulphur Sponge Iron

By R. C. Buehl and  
E. P. Shoub

**A** PRACTICAL method of producing sponge iron of low-sulphur content in rotary kilns from iron ore, and commercially available solid reducing agents has been developed by the United States Bureau of Mines. The new feature of the method consists in the use of a reducing agent prepared by heating an intimate mixture of coal and limestone in standard cooking equipment. Previously, a major difficulty in producing sponge iron to use as a substitute for steel-melting scrap has been the high sulphur content of the product obtained when coal or coke of the usual sulphur content is the reducing agent. Introducing lime, or limestone, into the feed of the kiln results in some decrease of the sulphur, and when low-sulphur coals are employed the sponge iron produced has a sulphur content of about 0.05%. However, coals with such a low-sulphur content are not available in many sections of the

country, and the addition of lime to the feed, when higher sulphur coals or their cokes are used, does not produce a sponge iron with the low-sulphur content desired for electric or open-hearth melting stock.

Recently, work was undertaken by the Bureau of Mines on the production of a low-sulphur sponge iron. These operations are being performed in a small internally fired rotary kiln capable of producing about  $1\frac{1}{2}$  tons of sponge iron per day. Specially prepared low-temperature coke with an average sulphur content of 0.9% was used as the reducing agent. Powdered limestone (rock dust) was intimately mixed into it to the extent of one-fifth the weight of the coal. This coke was

ground to pass a 4-mesh screen before being used in the kiln. Chateaugay ore, a New York magnetite, when reduced with this "lime coke," gave a sponge iron with a sulphur content ranging from 0.04 to 0.07%, and with an over-all average of 0.059%.

Laboratory tests have indicated that low-sulphur sponge iron can be produced by this method when non-coking as well as coking coals are used, even when the sulphur content is above that normally employed in ferrous metallurgical operations. The tests are being continued. The processes being developed are applicable to the production of sponge iron in standard internally fired rotary kilns, such as those employed by the cement industry.

## Effects of Various Elements on the Hardness and Rolling Textures of Copper

By R. M. Brick, D. L. Martin and P. P. Angier

THE work-hardening characteristics, softening temperatures and rolling textures of ten pure binary alpha-solid solutions of copper under controlled grain-size conditions, and at various solute concentrations, were determined. The alloys experimented with consisted of twelve copper-zinc alloys (0.94 to 38.3% zinc); six copper-nickel alloys (1.1 to 30.6% nickel); six copper-manganese alloys (1.02 to 10.03% manganese); five copper-aluminum alloys (0.55 to 7.99% aluminum); five copper-silicon alloys (0.11 to 2.34% silicon); five copper-arsenic alloys (0.47 to 4.98% arsenic); two copper-antimony alloys (0.75 and 1.2% antimony); two copper-cobalt alloys (1 and 1.56% cobalt); two copper-tin alloys (2.28 and 3.37% tin); and a commercial copper-nickel-zinc alloy (64.53% copper, 18.09% nickel, 16.50% zinc).

Castings were homogenized by heating from 4 to 400 hours at temperatures close to the solidus, depending on the kind and amount of solute present. Discs cut from the bottom third of the various ingots were cold-rolled to a reduction of 40%, annealed 1 hour at 700° C., rolled to a reduction of 20%, and annealed to a uniform 0.090 mm. grain size. For the solid-solution experiments, specimens were then annealed at the individual temperatures required to achieve a uniform 0.035 mm. grain size. Work-hardening

determinations were made by rolling to a reduction of 60%, taking hardness measurements at reduction increments of 10%. For softening data, individual specimens were annealed 1 hour at various temperatures from 100° to 800° C., and for the determination of deformation textures specimens were rolled to a reduction in excess of 95%, a thickness of about 0.035 mm. This latter material was subsequently annealed at temperatures giving a grain size of less than 0.010 mm. for determination of the recrystallization textures.

TABLE I.—RELATIVE ATOMIC VOLUME OF SOLUTE ELEMENTS.

Solute	Amount of Solute to Raise D.P.H. of Cu. 41 to 54 Atomic %	Hardness Increase per Atomic % D.P.H.	Atomic Volume Difference Solute-copper, cm. 3/gm. atom.	Solubility at Room Temperature Atomic %
Ni	13.2	1.0	- 0.5	100
Zn	12.1	1.1	+ 2.0	36
Al	4.7	2.7	+ 2.9	20
Si	4.6	2.8	+ 4.6	8
Mn	4.6	2.8	+ 0.3	24
As	3.6	3.6	+ 6.0	6.5
Me	1.7	7.6	+ 6.9	5
Co	1.4	9.3	- 0.5	1
Sn	0.9	14.0	+ 9.2	1
Sb	0.6	21.0	+ 11.1	0.6

The addition of a second element to pure copper results in an increase of hardness, which, for small additions, is linear with increasing solute concentration. Different elements—nickel, zinc, aluminum, etc.—produce hardening effects to a degree which depends primarily on the difference in atomic volume of solute and solvent, or

relatedly upon the parameter change of the solvent on the extent of solid solubility. The relative atomic value of the solute elements also affords a basis for partially systematizing their hardening effect and their solubility limits, as shown by Table I.

A straight-line relationship was found to exist between the solution-hardening characteristics of the different solutes. An element which produces a great solution-hardening effect will, correspondingly, greatly enhance the work-hardening properties of the copper.

The temperature range of softening of the cold-worked alloys could be defined by the change in the diamond-pyramid hardness impressions, from convex to concave sides, as well as by the temperature at which hardness is half-way between that of the cold-worked and that of the recrystallized alloy. Small, initial solute additions rapidly increase the softening temperature to a maximum at some intermediate alloy concentration, with a subsequent slight decline as the solute content approaches a maximum. The effect required the use of different annealing temperatures to ensure uniform grain size and comparative hardness data for different alloys of one system.

The effect of the solute element on the cold-rolling textures, as shown by pole figures, conforms to a simple pattern, in that only the copper, the brass, or an intermediate type of preferred orientation was found. In the copper-zinc series the most significant change in deformation rolling texture from the copper to the brass type occurred at about 5% zinc, while the corresponding change in recrystallized specimens occurred at about 1% zinc. Cold-rolled alloys of copper with manganese, aluminum, arsenic and antimony appeared to behave, structurally, in a manner similar to that observed in copper-zinc alloys. Alloys containing cobalt or nickel showed only the copper texture, while those with silicon, magnesium, tin and the copper-nickel-zinc alloy showed only the brass texture. The cold-rolled preferred orientations thus fitted a rather simple pattern.

The recrystallization textures of the alloys examined were not so uniform. Elements such as arsenic, antimony, tin and magnesium, which conferred the greatest solution or strain-hardening on copper, showed the most complicated annealing textures actually equivalent to a less marked degree of preferred orientation.



## The Problem of Waste Gas Heat in Swedish Iron Works

By Lage Malm

IN the present circumstances the saving of fuel in Sweden is a vital necessity. Large quantities of heat, mainly in the form of hot-exit gases, are lost from the heating furnaces and open-hearth furnaces, and partly in the form of blast-furnace gases. This heat could be used to produce steam for forging, local heating, etc. In Sweden 278,000 metric tons of coal, or its equivalent, are consumed per year in blast furnaces, electric furnaces, open-hearth furnaces, and heating furnaces for rolling and forging. It is considered that with suitable methods at least 200,000 tons per year could be recovered.

fortunately, the costs of installation are high. When steam is produced for indirect purposes it is only possible to make considerable use of it during the cold part of the year, whereas when the heat is used for air heating, the availability of waste heat varies with the requirement of hot air.

Considering the question of economical extraction, the longer the pipe conveying the waste heat to the medium to be heated up the greater the heating area, and the greater the transfer, but the profit deriving from the recovery of heat must be balanced against the cost of the pipe-line.

An installation in actual use is

shown in diagram form in Fig. 1. R 1 is an air heater of normal carbon steel for heating the air to 300° C. in series with another heater of hardened steel for heating to 450° C. KD 1 and KD 2 are steam producers; from KD 1 the steam passes to OH, where it is superheated. The temperatures of the waste gases at the various stages are as shown. The air enters at 25° C. and the water at 105° C.

Much depends on the use of suitable baffle-plates in the regenerators to canalise the stream of hot air against the surfaces across which the heat is transferred.

On account of the seasonable variation in heat requirement, alternative methods of using the heat have been tried. In an installation attached to an ironworks and forging plant, part of the steam is used to drive a turbine for the production of electrical energy.

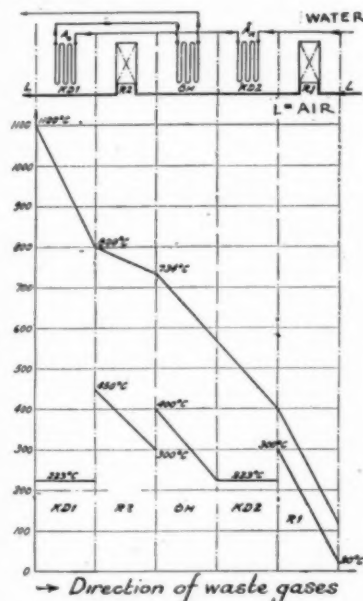


Fig. 1.—Diagram showing arrangement of regenerators and temperatures.

Recovery plants for the production of steam and hot water for indirect purposes, such as local heating, are the most common at the moment, but the preheating of producer-gas air is also a practical possibility.

The relative costs of running a steam boiler with coal and wood against those using exit gases at various temperatures from about 600° to 1,200° C. from various types of furnaces were considered, and it was shown that the recovery was profitable. Un-

## The Salt-Spray Test as applied to Electro-Deposited Metal Finishes

By C. H. Sample

THE basic features of salt-spray testing consists of exposing suitable specimens to a fog or mist formed by atomising a solution of common salt. The introduction of this test to industry was occasioned largely by the incorporation of salt-spray test requirements to various Government specifications in an effort to ensure a quality of product capable of withstanding severe service conditions. The relatively rapid and widespread conversion of industry to war production, with the attendant increase in the use of those specifications containing salt-spray test requirements, has forced a greatly increased use of a test which, in the considered opinion of many, is of doubtful merit. It is, therefore, considered necessary to point out the accepted uses and limitations of the salt-spray test, together with the pertinent factors which should be required in establishing such test requirements in specifications.

The protective value of electro-positive metallic coatings is a function of their thickness, and an inverse function of their degree of porosity, while the protective value of electro-negative coatings is directly proportional to their thickness. The protective value of any particular coating, however, varies considerably with the

environmental conditions to which it is exposed, and if the salt-spray test is to be of value in determining whether or not any particular coating is suitable for any particular application, correlation of the test results with service performance must be established.

In general, it has been found that, when thoroughly standardised and properly conducted, the salt-spray test is useful in evaluating the degree of porosity of electrodeposited metallic coatings of the electropositive type, such as nickel-chromium coatings on steel or zinc, respectively. Tests have shown that the time of exposure to the salt spray required to reveal a certain degree of porosity varies with the coating-base metal combination being tested, and should be correlated with actual exposure tests, and that the time required for "first rust" to appear is not as important as the appearance of the coating after a given length of time in the salt spray. For electronegative type coatings, the salt-spray test cannot be recommended as a quality test, as more reliable test methods are available.

Limitations of the salt-spray test are found in its technique, the qualitative-ness of the results obtained, and the lack of fundamental knowledge regarding the behaviour of different coating-base-metal combinations under the

From Bulletin, American Society for Testing Materials, 1943, No. 123, pp. 19-21.

conditions of the test. As regards technique, investigations have shown that solutions and concentrations being used range from natural and synthetic sea-water to saturated sodium chloride, temperatures of operation vary from uncontrolled room temperatures to 150° F., air pressures used to atomise from 8 lb. to 80 lb. per sq. in., the size of test chambers to vary considerably, the position of test specimens to vary from the horizontal to the vertical, and the exposure period to vary from 1 to 500 hours. Further standardisation is, therefore, considered necessary to reduce the number of variations permissible, and individual users should endeavour to standardise

equipment and exposure technique. Further, experimental data correlating salt-spray and service behaviour is also considered necessary to merit a more extensive use of the test.

A primary factor to be considered before incorporating the salt-spray test in a specification is whether such a test is capable of yielding reproducible results when performed at different times and by different users, and also whether it is a true measure of the factor it is intended to control. If such conditions are satisfactory, the maximum service requirements of the finish should then be considered in relation to the cost and practicability of obtaining such a coating.

## Spectrographic Determination of Molybdenum and Tungsten in Ores

By C. Georg Carlsson

**T**HE chemical determination of low molybdenum and tungsten percentages in ores is somewhat difficult, and there are many sources of error. Tungsten and molybdenum usually occur together and in amounts of the same order. The regions of low percentage are the most difficult to deal with chemically, and the easiest spectrographically. The regions examined were 0.1-0.5% MoS and WO<sub>3</sub>. (The determinations were, of course, made as Mo and W, but the percentages are given in this form in accordance with normal practice.)

The method normally used for ores is that described by Goldschmidt. The finely powdered material, usually mixed with carbon powder, is packed into a hole in the centre of a carbon rod, which is made the cathode in a d.c. arc. On account of the "cathode-layer phenomenon" the method is highly sensitive to low percentages of elements. With tungsten, however, the difficulty is that the best spectrum line at 4008.75 is obscured by the CN band spectra produced by the carbon. One method of reducing this disadvantage is to mix alkalis with the powder. This has the effect of reducing the temperature in the arc, and thereby of reducing the intensity of the carbon band, but not of the tungsten line. Unfortunately, many other lines are reduced to the same extent as the CN band, and this method is thus not of general application.

To avoid these troubles, electrodes

of other materials, e.g., copper, may be used. This has the advantage that the special purification necessary for the carbon rods is avoided. 3 mm. dia. copper electrodes were used by the author, with axial holes 2.6 mm. dia., 2 mm. deep. The powder is packed hard in the hole, and the arc current adjusted so that the material just fuses. With a deeper hole, part of the drop runs out of the hole and away from the tip. With a lower temperature the specimen is solid and the arc plays mainly on the copper rim instead of the material. In order to reduce the melting point, alkali and alkaline-earth salts may be incorporated (see also below).

To attain high temperatures without the copper electrode melting, the electrode should be water-cooled or the arc made intermittent to allow the electrode to cool down in between. The latter method gave more reproducible results. The arc was interrupted 100 times a minute, the duration of each pulsation being 0.2 sec.

With the copper electrode better results were obtained by making it the positive. A carbon rod, 7 mm. dia., was made the negative. The carbon bands were too weak to be important, and the carbon counter electrode was found, in practice, to be better than one of copper.

The emission from the centre of the arc was used. The light passed through a rotating three-step sector, ratios 1 : 3 : 9, to a Hilger E 478 spectrograph, with a glass optical system, dispersion 4A/mm. Agfa Spectral Blau Hart plates were used, the

exposure being 2 mins. The line densities were measured with a microphotometer, and a calibration curve using known standards was drawn. The usual method, comparing the density of the line of the element under consideration with a line of an element whose percentage in the material was constant, was not used, since it was found, firstly, that quite good results were obtained using the line densities directly, and, secondly, that the emission of the iron lines varied to a greater extent with arc variations than did the molybdenum and tungsten lines.

It is known that the composition (i.e., other than W or Mo) of the test sample has an effect on the line densities, and thus the standards should resemble as closely as possible, in this respect, the routine samples. The ores under consideration are mainly quartz and felspar, and so a powdered granite was used as the standard base and blended with appropriate quantities of chemically pure W and Mo oxides. In the final test, standards and synthetic routines were mixed with a powder containing FeO and calcium, sodium and potassium salts to even out the effects of variations in these elements from sample to sample. Large variations in Si, Al, Ca, K and Na were then found to be without effect on the analyses except with calcium or tungsten. Here the accuracy was lower, and it would be necessary in practice to make special standards to cover this case if it arose frequently.

The lines used were: Mo, 3864 Å; 4233 Å; W, 4009 Å. The reproducibility was better with the first molybdenum lines. The method was available down to 0.005% MoS<sub>2</sub> and 0.01% WO<sub>3</sub>.

## Biological Mining to Supplement Dwindling Ore Reserves

**F**UTURE generations may perhaps obtain from the sea part of the vast supply of elements needed, as we now get some of our magnesium and bromine, instead of utilising the diminishing ore reserves (biological mining). Manganese occurs as pyrolusite in large deposits on ocean floors, the exact origin of which is unknown. One hypothesis suggests that they may have been formed by the remains of animal organisms which had manganese

From *Jernkontorets Annaler*, vol. 127, No. 11, p. 572, 1943.

From *Industrial Bulletin*, Arthur D. Little, Inc. October, 1943.

instead of iron in their tissues. It has been suggested, too, that even land deposits of pyrolusite may have had their origin in the life cycle of marine animals in prehistoric seas.

The skeletons of many species of diatoms are finely divided pure silica. Oyster shells form an immense reserve of pure calcium carbonate. Some radiolarians have shells of strontium carbonate instead of the usual calcium carbonate. The amount of strontium in the ocean has not been detected by chemical means, yet these animals have power to obtain it in high purity. Vanadium is another element concentrated by an ascidian, and by a holothurian (sea slug) found off the Cornish coast. Iodine, although present in only minute traces in the ocean, is concentrated in certain seaweeds and has been extracted commercially from their ash. Seaweed is used in Ireland as a fertilizer because of its high concentration of potassium. The blue blood of lobsters and king crabs is due to the presence of copper instead of iron, and organic copper salts in marine organisms are of great use in treating pernicious anemia. Arsenic too, is found in several of the ocean crustaceans.

The plant *Astragalus pectinatus* takes up selenium from the soil. There is also geochemical interest in the concentration of radioactive mesothorium by a pond plant. Plants which extract gold from the soil, such as the horsetail, are known, and when burned their ashes may serve as an indicator to prospectors. A fortune may be awaiting the biologist who develops a seaweed which likewise uses gold in its tissues. A sea organism which concentrates tin would be of more intrinsic value to-day, and it is not entirely out of the question, because there is a certain species of yellow violet which grows only where it can get tin.

## Magnesium Production Processes

THE magnesium process used by Basic Magnesium, Inc., in Nevada, is essentially that developed in Germany for the electrolytic reduction of magnesium chloride,<sup>1</sup> produced from magnesium carbonite (dolomite or magnesite). The raw material is mined by open-pit methods, and about 1.5 tons of waste must be moved to secure 1 ton of ore. The ore is delivered by truck to the plant several miles

distant, where it is crushed, calcined and subjected to flotation, after which it is mixed with coal and made into small pellets with magnesium chloride. These are treated with chlorine to form anhydrous magnesium chloride, which, when electrolysed, produces magnesium metal (98% Mg) and chlorine.

At Permanente, California, a large tonnage of magnesium is now being turned out with no fires.<sup>2</sup> The process is essentially that developed by the Austrian, Hansgirg, in which magnesium oxide is reduced by carbon to produce magnesium vapour and carbon monoxide. The metal vapour is shock-chilled with natural gas. Calcined

dolomite is used as the raw material, and is treated in the Kaiser sea-water plant to produce magnesium oxide 96% pure. About 900,000 cub. ft. (25,500 m<sup>3</sup>) of natural gas is fed into the furnaces every hour.

The most important recent advance in the Pidgeon process is the development of a continuous furnace and a successful condenser.<sup>3</sup> Silicon is used as the reducing agent in this process; ferrosilicon and magnesium oxide are mixed and briquetted and then heated in a 10-in. (25-cm.) retort under a vacuum of 100 microns. The magnesium thus produced is 99.7 to 99.8% pure.

## Procedures for Testing Metallising Bonds

By H. Ingham and K. Wilson

IN order that consistent results can be predicted on a uniform basis, efforts are being made to develop standard testing procedures acceptable to the metallising industry. As there are several methods of bonding sprayed metal, to fulfil their objective, test procedures must first prove an accurate means of comparison of different methods of bonding. Secondly, they must provide accurate values in pounds per square inch for each bonding method and for each metal used.

The nature of the failure of the bond between sprayed metal and base metal is somewhat complex. The most common failures occur either on flat or nearly flat surfaces, or shafts which have been cut with a keyway. In both cases most failures occur first by a shearing of the bond due to a shrinking of the sprayed metal layer. This shear action is not necessarily sufficient to cause complete failure, but may simply weaken the bond. After the bond is weakened, the final failure is a failure of the bond in tension as the sprayed metal layer is lifted off either by the curling action resulting from shrinkage or by actual mechanical means. This would depend upon the service encountered. Because this type of failure caused by the shrinkage of the metal is the most common, the strength of the bond in shear is most important. However, as both shear and tension affect the bond strength, methods for testing both have been developed.

The proposed standard bond test shear specimen is shown in Figs. 1 and 2, together with all dimensions and tolerances. A cylindrical specimen is

used because this shape lends itself best to the application of all bonding methods, including those obtained by various methods of machining. Bar material is used approximately 1 in. diameter. This is machined to the diameter listed in Fig. 1. The length of the specimen may be varied according to the method of machining.

The specimen is prepared for bonding sprayed metal by the method being tested, throughout its entire length. Preparation and spraying conditions are under strict control and approximate the conditions it is desired to test. After spraying to 1½ in. diameter over the entire area, the specimen is machined to the dimensions given in Fig. 2. A slot is sawed completely through the sprayed coating into the base material, the purpose of which is to eliminate any bond between the coating and the base which might result from shrinkage of the coating.

A shear block is prepared as in Fig. 3, and the specimen assembly placed in the die block located in the compression testing machine, as shown in Fig. 4. Occasionally pieces of the coating will break and fly off when the bond is broken, thus a guard should be provided at the front of the press.

The length of the sprayed coating B in Fig. 2 is preferably 0.500 in., but in some cases the bond strength at this length may exceed the capacity of the testing machine; in such cases, length B may be 0.333 in. When the specimens have dimension B equal 0.5 in. the bond area is 1.5 sq. in. and 1 sq. in. when B is 0.333. Thus the total load required to shear the coating divided by this factor equals the shear strength in lb./sq. in.

<sup>1</sup>From papers presented to the Institute of Metals and Iron and Steel Divisions, Oct., 1943, by: (1) Ball, Rasse, and Donohoe; (2) T. A. Dungan; and (3) R. L. Sebastian.





pulled out of the shaft in a testing machine. With the dimensions of the shaft, coating thickness, and stud diameter properly proportioned, failure of the bond takes place on the end of the stud. Actual dimensions of the tension test blank is shown in Fig. 6, and specimen stud or plug in Fig. 7. The blank should be made of mild steel, and specimen plug made of the base material to be tested. Plug is assembled in the blank and fastened by the set-screw shown in Fig. 5.

With the plug firmly secured in place, the surface of the blank is prepared for spraying by any desired method. After preparation the plug is taken out of the blank and removed of burrs caused by preparation—enabling the plug to slide freely in the hole. Both blank and specimen must be kept scrupulously clean. Before spraying the plug should be replaced in the blank in exactly the same position it occupied previously. A spraying mask, illustrated in Fig. 8, is then screwed into the end of the stud at A, Fig. 5. Specimen is then sprayed in a lathe with metal selected for the test.

After spraying, the mask is removed and the specimen machined or ground to a diameter of 0.170 in. larger than the diameter before spraying. The specimen is then assembled in the test rig as shown in Fig. 9. After screwing the pull-bar on to the specimen plug, set-screw shown in Fig. 5 should be removed. This screw should not be removed earlier, as there is danger of damaging the bond when assembling into the rig. Rig is then mounted in the tensile testing machine. As the prepared area of the specimen plug is 0.196 in., breaking load as indicated on the testing machine multiplied by 5.1 will give tensile strength of the bond in lb./sq. in.

The test results obtained from shear and tension bond tests have two very important uses. One is for comparing values between methods known from experience to be satisfactory and new methods or variations of methods which it is desired to use. The test results have relatively little value in an abstract sense, since the internal forces of the sprayed metal which cause the failure are not known. The other important use is for control of the surface preparation method in the shop by checking an operator technique and on equipment and supplies used. The test for bond, for instance, is the only adequate means of testing the effectiveness of blasting grit.

The authors point out that good

bond strength are easy to obtain and are desirable, if not always required, for all heavy coatings on machine-element work. Therefore, the main

use of bond tests is to help in obtaining and maintaining good bond strengths by the proper selection and control of bonding methods.

## Metallurgical Problems arising from the use of Copper in Electric Equipment

By E. R. Parker

**P**URE copper is used extensively in electric equipment because of its high conductivity. The tensile strength of copper is low and its specific gravity is high, so that it is generally unsuitable for structural use. However, some of the alloys of copper exhibit exceptionally good mechanical properties (for example, beryllium copper) and are widely used for structural purposes. Copper used for electric conductors must be of high purity. The total of the metallic impurities in both tough-pitch and oxygen-free high-conductivity coppers should be less than 0.01%. Small amounts of impurities may greatly reduce the electric conductivity of copper and thus limit the efficiency of electric equipment.

The conductivity of high-purity copper is affected strongly by cold working. For example, when the cross-sectional area is reduced 85% by cold drawing, the conductivity drops from 102.3 to 100.0%. Consequently, annealed copper is used whenever high conductivity is desired. Small amounts of impurities also have profound effects on the annealing characteristics of copper. Some impurities greatly affect the softening temperature, particularly tellurium, of which as little as 0.001% is sufficient to raise the softening temperature about 80° C.

Certain applications of copper require operating temperatures above those normally employed. Under the influence of stress at high temperatures, copper often breaks with very little elongation. The apparently "brittle" failure follows the grain boundaries of the copper instead of going across the grains as a normal ductile failure does. The intergranular type of failure can occur in equipment operating at temperatures above 125° C. whenever the copper is subjected to prolonged loading. At higher temperatures, such fractures occur with lower loads and in shorter times, often without warning or noticeable deformation. Such

failures can be eliminated by judicious balance of the impurities present in the coppers.

High-purity copper is very weak at 200° C. Commercial tough-pitch copper, which contains about 0.01% metallic impurities, is considerably stronger. The addition of 0.039% silver to the tough-pitch copper greatly improves the high-temperature strength and practically eliminates the undesirable intergranular fractures. Small quantities of other elements, such as cadmium and manganese, also greatly improve the high-temperature strength without lowering appreciably the conductivity. There are many applications where a high-softening temperature (often associated with good high-temperature strength) is very undesirable. One such instance is in the annealing of hard-copper wire during the baking of the enamel in the enamelling process. The wire is run continuously through the enamel and then directly into the baking oven. If the baking and softening can be done simultaneously, soft-copper wire can be produced more rapidly and cheaper than if a separate annealing operation were necessary. The baking temperature is limited by the enamel, which must be "burned" in the operation. Small amounts of impurities, particularly tellurium, antimony and cadmium, prevent copper from softening. Consequently, great care must be taken to remove these elements during the copper-refining process whenever the copper is to be used in the enamelling process.

Whenever copper containing copper oxide is heated in an atmosphere containing hydrogen, the hydrogen may diffuse into the copper, unite with the copper oxide and form water vapour which cannot escape. The water vapour expands and causes large holes to form, thus embrittling the copper. Embrittled copper is very weak and has extremely low ductility. Consequently, contact with hydrogen must be avoided in the fabrication of

tough-pitch copper. Oxygen-free copper is used whenever the copper must be heated in contact with hydrogen.

An interesting problem that as yet has not been solved is that of the copper-oxide rectifier. The metallurgical requirements of copper for good rectifiers are not clearly understood. Some coppers are good; others, for no apparent reason, are bad.

### Rapid Determination of the Magnesium Content of Al/Mg Alloys

THE magnesium content of Al/Mg alloys can be determined by X-ray diffraction, since the lattice constant of the  $\alpha$  mixed crystal increases with increasing Mg content. For a successful determination the following conditions must be fulfilled:

- (1) Complete solution of the Mg in the  $\alpha$  mixed crystal.
- (2) Uniform distribution of the Mg.
- (3) Fine-grain structure of the sample.

The simplest method for achieving this is to take a small sample of the liquid melt in an iron spoon (previously heated to the temperature of the molten alloy) and scatter it on a well-conducting metal plate. The resulting discs of metal of about 0.1 to 0.2 mm. thick are annealed in a salt bath for 5 mins. (the temperature of the bath being just under its melting point), and then quenched in water. The lattice constant is best determined by means of an electronic (Geiger) counter, and the corresponding Mg content follows from calibration curves.

The analysis takes about 20 mins., and is accurate to a small multiple of 0.01%.

Translation of original digest from Z.F.D.J., 1942 55, 558, by courtesy of R.T.P. 3, Ministry of Aircraft Production. (Original article in Z. Metallkunde, 1942, 34, 114/116.)

### Tempering of High Carbon High Chromium Steels

THE results are given by O. Zmeskal and M. Cohen of a study of the kinetics and mechanism of the structural changes which accompany the tempering of 1% carbon, 5% chromium and of 1.5% carbon, 12% chromium tool steels by means of magnetic dilatometric and X-ray measurements. Austenitising temperatures employed were 925° to 1,205° C., and in addition to quenching in oil, air and lime, tempering temperatures from 20° to 650° C. and tempering periods of several seconds to several hundred hours were also investigated.

Trans. Am. Soc. Metals, June, 1943.

Generally, hardened steels contain tetragonal martensite, retained austenite and undissolved alloy carbides, and during the early stages of tempering, the martensite decomposes from tetragonal to cubic followed by the precipitation of non-ferromagnetic carbides.

## The Effect of Annealing Temperature and Period on the Softening of Previously Cold-Worked Metal

By A. Pomp and G. Niebch

EXPERIMENTS were carried out on Krupp soft steel of the following % composition:—

C. 0.08 .. S. 0.05 .. Mn. 0.06 .. P. 0.005 .. S. 0.01 .. Fe. rest

The material was available in the form of round bars of 26 mm. diameter which were cut into 40 cm. lengths and annealed at 900° C. for 30 mins. The bars were subsequently cooled in kieselguhr (infusorial earth) and ground down to 18 mm. diameter.

The specimens so obtained were next stretched in a 35-ton tensile machine, so as to exhibit permanent reduction in cross-section of 5, 7.5, 10, 12.5, 15 and 20% respectively. The bars were then cut into cylindrical blocks, each 10 mm. high and annealed at a series of constant temperature ranging from 620° C. to 900° C., the annealing time varying from 10 mins. to 8 hours. Subsequent cooling took place either in still air or at a very much slower rate in the oven (1° C./min.). The blocks were then finally split longitudinally, and the Brinell hardness determined at 2 points for each of the two new internal surfaces thus formed.

These surfaces were then polished and etched for micrographical examination of the structure.

Immediately after cold-working and before the subsequent annealing, the material gave the following hardness values:—

Reduction in Area, %	Brinell Hardness 2.5/30 (2.5/30)
0	93
5	121
7.5	129
10	136
12.5	142
15	149
20	160

With annealing, some or all of this strain-hardening disappears.

The experimental results are given in graphical form, the Brinell hardness being plotted against annealing period for each temperature, with degree of original cold working (% reduction in area) as parameter.

From Z. f. Metallkunde, vol. 33, No. 5, May, 1943, pp. 111-117. By courtesy of R.T.P. 3, Ministry of Aircraft Production.

Basically, the mechanism of the tempering process in these chromium tool steels is consistent with that reported for high-speed steel, but it is more varied in its details, due to the wide range of retained austenite contents and stabilities obtainable in the chromium steels.

Broadly speaking, the curves fall into two classes, depending on whether the original cold working amounted to less or more than 10% reduction in cross-section.

(1) In the former case, after an initial rapid softening of the material a steady state is reached in about, 30 mins. and extending the annealing period to 8 hours causes no further reduction in hardness. The final value, moreover, is still appreciably above that of the original material prior to cold working. (Brinell 115, against 93.)

(2) If, on the other hand, the material has been stretched to give a reduction in area between 10 and 20%, the softening during annealing is progressive over much longer period (of the order of 4 hours), and the final hardness figure is practically identical with that of the original material prior to cold working.

It appears that in the case of moderate strain-hardening the subsequent softening on annealing is mainly due to crystal recuperation and metallographical examination shows no change in structure of the material.

With high degrees of original strain-hardening, however, marked recrystallisation of the material takes place on annealing.

### Phosphatising in the Cold

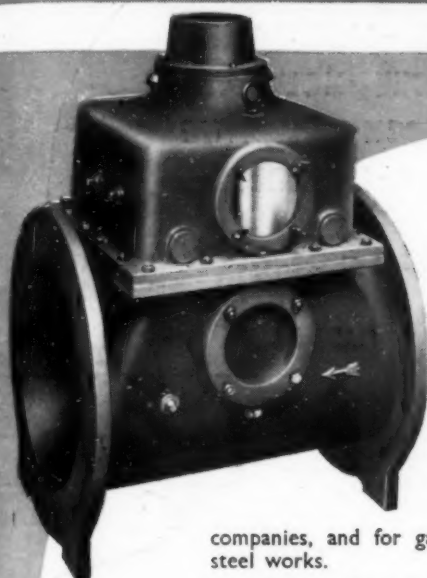
IN the well-known phosphatising (anti-rust) process, bath temperatures of the order of 90°-95° C. were employed originally. It has been found that equivalent results can be obtained in the cold, if sodium nitrite is added as an accelerator to a zinc phosphate bath (pH = 2.7). The process has been worked on a large scale for over two years, and led to a saving of several thousand tons of coal per month.

From Z. F.D.J., vol. 87, No. 49-50, Dec. 11, 1943, p. 974. By courtesy of R.T.P. 3, Ministry of Aircraft Production.



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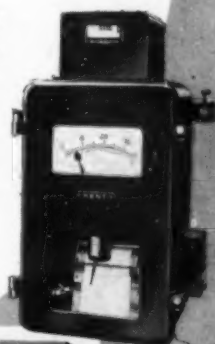
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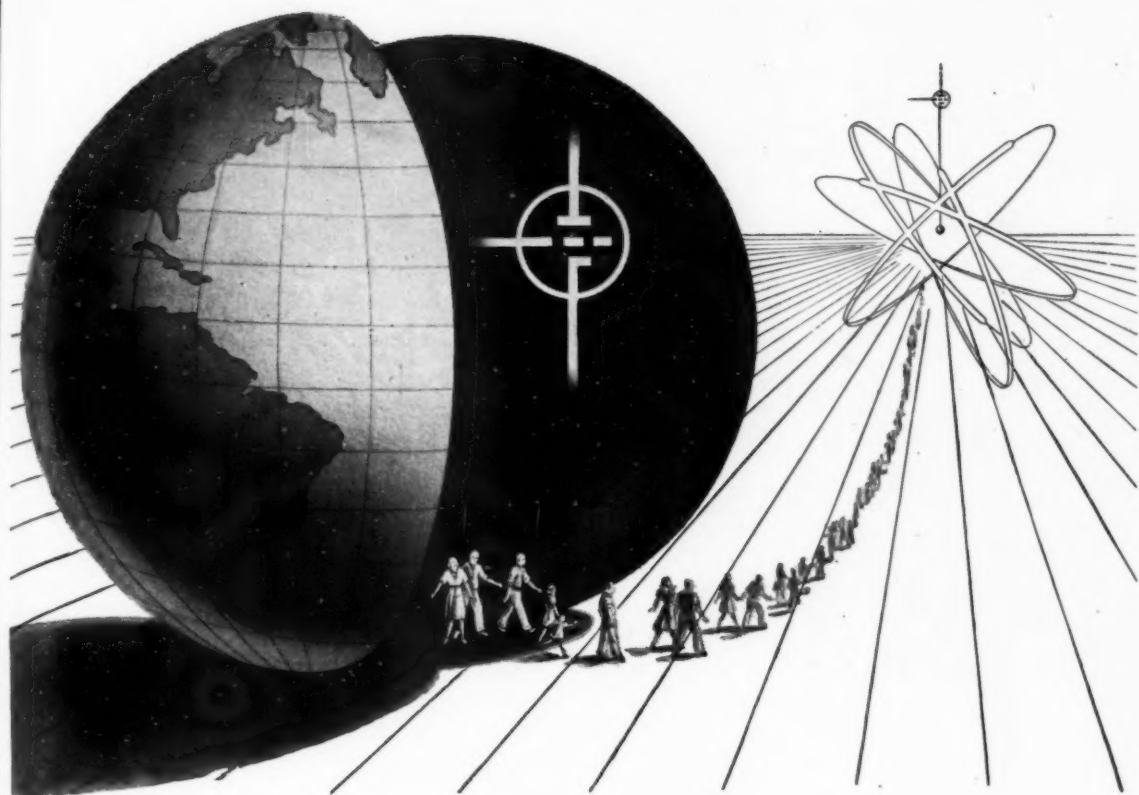
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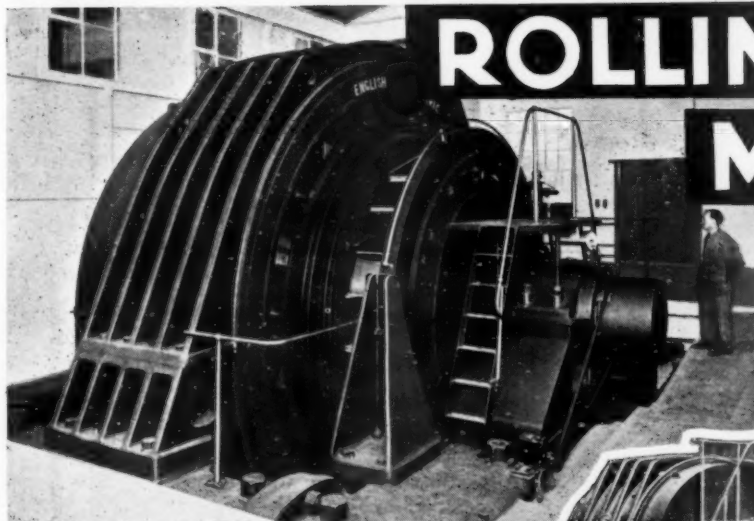
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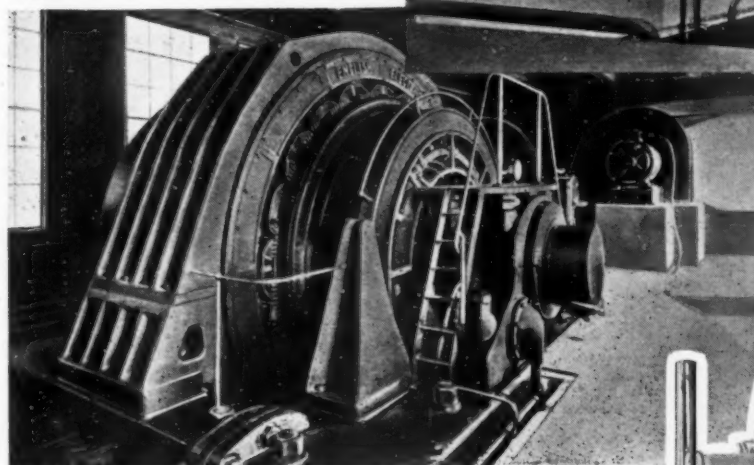
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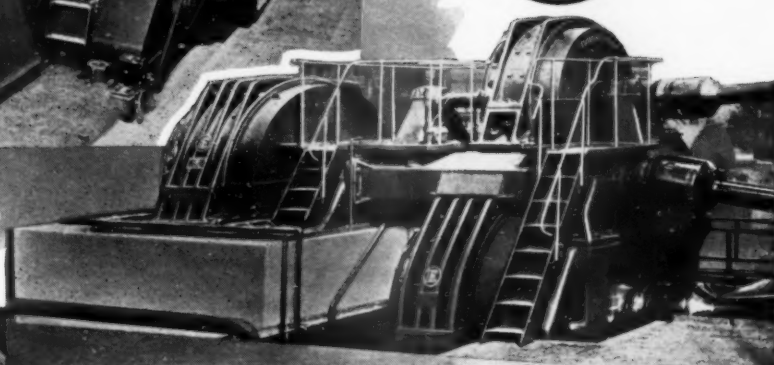


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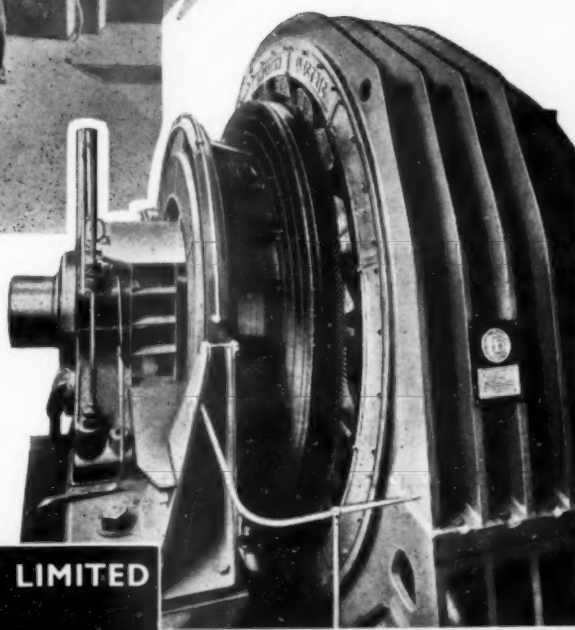


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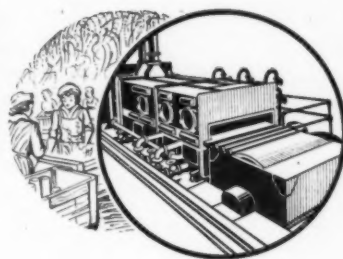
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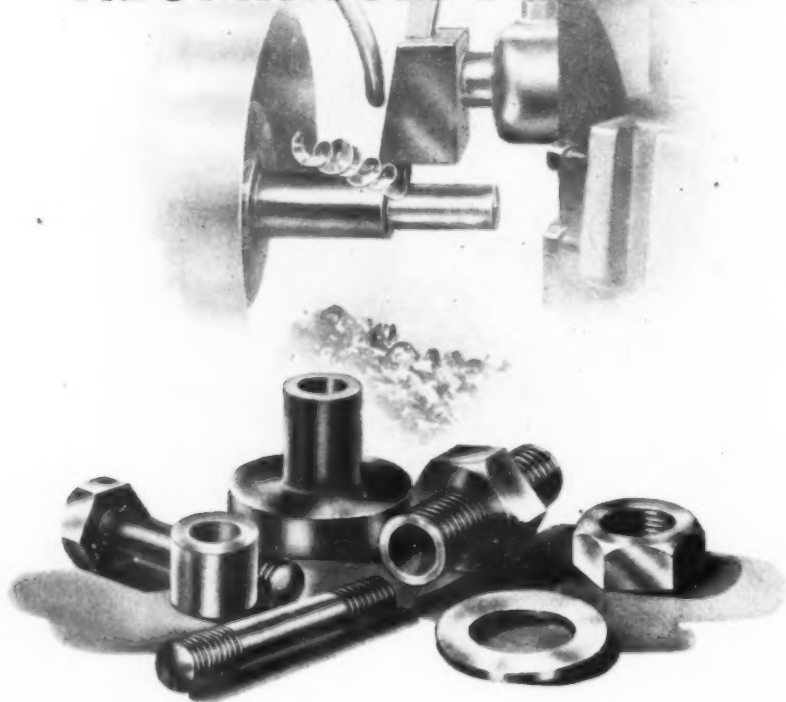
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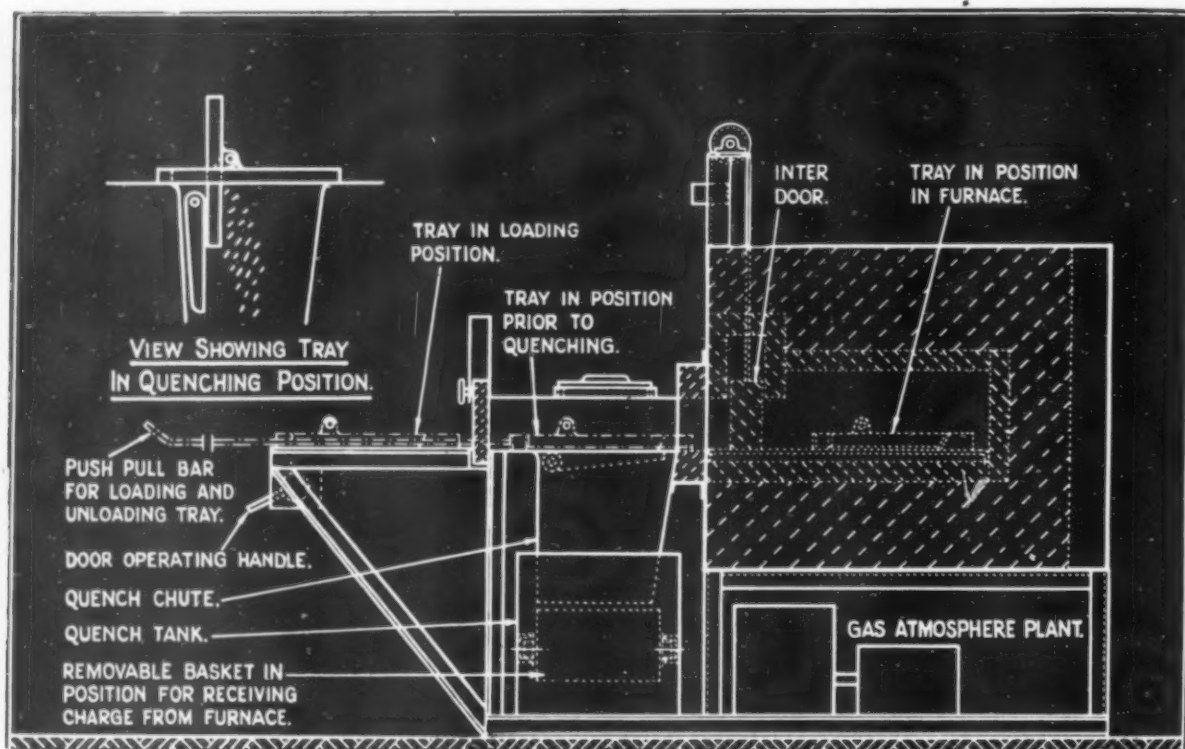
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The equipment comprises a gas-tight furnace with gas-tight vestibule, chute, quench tank, special hinged tray, automatic temperature control gear and controlled atmosphere plant.

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The equipment is primarily intended for bright hardening, but can also be used for bright annealing, copper brazing and other heat-treatment operations. When used for bright annealing and copper brazing the quench tank is not used and the charge is allowed to cool in the vestibule after heating.

### METHOD OF OPERATION.

The charge tray has a hinged bottom and is fitted with a bar for charging and discharging purposes. This tray is loaded with work whilst on the platform in front of the vestibule. It is then pushed into the vestibule over the quench tank, the inner door raised and the tray again pushed, this time straight into the heating chamber. The inner door is closed. When the charge has been in the furnace for the required time, the inner door is again opened and the loaded tray withdrawn into a position directly over the quench tank, where it automatically tips, ejecting the parts into the quenching medium before any serious drop in temperature of the charge has occurred. The tray itself is automatically returned to horizontal as it is withdrawn for recharging. The work is in the protective atmosphere during the whole cycle.

To prevent the charge being ejected into the quench tank whilst being pushed into the heating chamber, a safety device is fitted locking the quench levers in the horizontal position. This is released when the charge is to be quenched.

# ELECTRIC RESISTANCE FURNACE CO. LTD.

NETHERBY, QUEENS ROAD, WEYBRIDGE, SURREY

Telephone: Weybridge 3816



Many factories in this country—too many—are still without Power Trucks. In these factories Power Trucks would

- Speed up movement of material and work in progress
- enable ONE girl to do the work usually done by TEN men
- cut out intermediate handling so that Movement can ANTICIPATE Processing.

Write for particulars of the Douglas Truck-Stillage system—the Advanced Striking Force of the Factory Front.

# Douglas

Regd. Trade Mark.

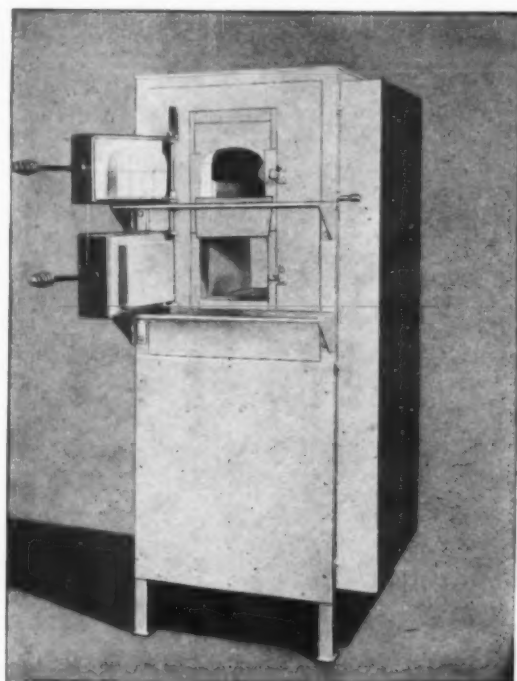
## INDUSTRIAL Power TRUCK

DOUGLAS (KINGSWOOD) LTD., P.O. Box 1T, KINGSWOOD, BRISTOL. (Tel. 73013)  
Export Div.: Engineering & Aviation Exports, Ltd., 50, Pall Mall, S.W. 1. (Tel. ABhey 6210. Cables 'Aeragal,' London.

# ELECTRIC FURNACES

FOR THE HEAT-TREATMENT OF STEEL

Temperatures up to 1,350° C. obtained by means of  
Patented Metallic Heating Elements



Tool Hardening Furnace  
Rating 8 Kw. + 5 Kw. Heating Chambers 14" x 7" x 6"

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PRECISION  
BALANCES  
AND  
WEIGHTS

THE FINEST

*Quality*

IN THE WORLD

CHEMICAL BALANCES  
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ASSAY BALANCES  
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BULLION BALANCES  
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PRECISION WEIGHTS

Please request detailed list.

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FOUNDED  
IN LONDON  
BEFORE 1847



# STEIN

## Basic Refractories

JOHN G. STEIN & CO. LTD.

JOHN G. STEIN & CO. LTD.

TYPICAL FURNACE WALL FILLING, 14 ft. high, 14 ft. wide, 14 ft. deep, 14 ft. long, 14 ft. high, 14 ft. wide, 14 ft. deep, 14 ft. long.

TYPICAL OPEN-HEARTH FURNACE with fully sloping back wall.

STEIN KM

STEIN CHROME

STEIN MAGNESITE

Four worthwhile applications of "STEIN KM" Chrome Magnesite Brick in the Open Hearth Furnace are—

- 1 As a CENTRAL PANEL in the Back Wall over the tap hole, to reduce the scouring action of the siliceous wash.
- 2 In the FURNACE HEARTH, similar to U.S.A. practice. One user has just converted his fourth furnace in the last three years to a "STEIN KM/STEIN CHROME" Bottom, using Magnesite only in the tap-hole area.
- 3 A FACING to the BLOCKS which serves to maintain the direction of the flame throughout the furnace campaign.
- 4 In the WING WALLS, where "STEIN KM" gives protection to the Back and Front linings.

JOHN G. STEIN & CO. LTD.  
RONNYBRIDGE SCOTLAND

# ONE MORE MOVE

The "FESCOL" process of electro-deposition of metals is salvaging much of the incorrectly machined material which, otherwise, would be designated scrap—with a consequent loss of man-hours, materials and money. And, moreover, the "FESCOL"-ised surface will always prove superior to the basis metal—wear-resisting and non-corrodible. "FESCOL"-ising is a move to check waste. We have technical staff in various parts of the country who will be glad to advise you on applications of the process. Responsible executives may have fully descriptive list M.U.3 on request.



**FESCOL LTD**

*Originators of Electrochemical Deposition*  
NORTH ROAD, LONDON N-7

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and  
**Harper-**  
**Meehanite**  
*Castings*



# GETTING UNDER THE SKIN

Write for Technical Booklet:  
"THE SPECIFICATION OF  
MEEHANITE METAL."

Time and again we have stressed the benefits of the "Harper Skin." But someone said the other day, "Yes—but it is what's under the skin that matters." So here we show a Harper Casting that has been machined all over by a very intricate series of operations. Proof of the all-the-way-through quality of the casting.

JOHN HARPER & CO. LTD. • JOHN HARPER (MEEHANITE) LTD. • ALBION WORKS • WILLENHALL

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## *In my factory...*

*If only by easing the burdens of labour, light alloys will pay their way. Besides this they will save power, overcome corrosion. Used architecturally they will symbolise a better age when lightness and cleanliness go with strength and beauty. These, too, are reasons why 'INTAL' are so proud to be makers of aluminium alloys for every conceivable purpose.*

# *International Alloys Ltd*

SLOUGH, BUCKS

TELEPHONE: SLOUGH 23212

**INTAL**

WIRE: INTALLOYD SLOUGH





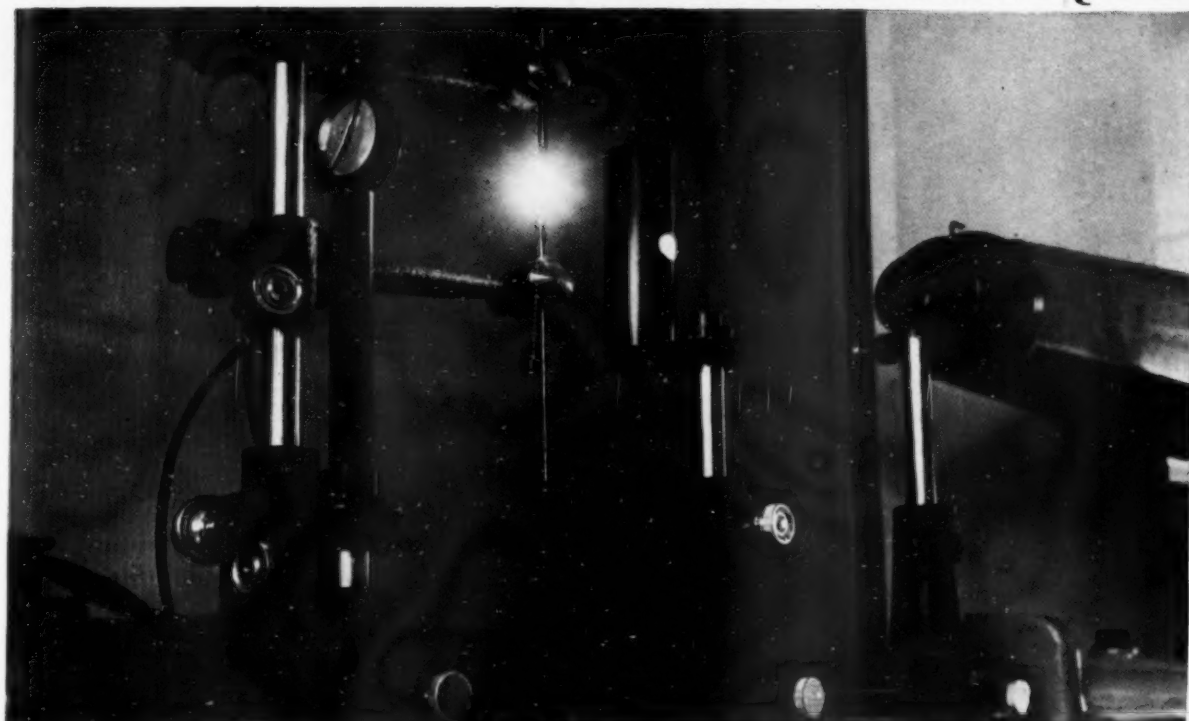
## ***You can have it both ways!***

There is something to be said for the conservative method of manufacturing pig iron with plenty of limestone in the charge—it does keep down the sulphur content of the iron. There is a lot more to be said for the modern tendency to operate the blast furnace with a leaner burden and thus increase output—maximum iron production needs no brief in these days. No, we are not overlooking the resulting additional sulphur pick-up, but *you* can—if you treat the iron in the ladle with Sodium Carbonate. In the case of most grades of cast iron, treatment in the ladle with 1% dense sodium carbonate removes 50% of the sulphur present in the metal. Simple, effective, economically increased output.



IMPERIAL CHEMICAL INDUSTRIES LIMITED

## LIGHT ALLOY CASTING TECHNIQUE



Production at Kent Alloys is founded on a basis of accurate laboratory control at every stage. It is the spectrographic control of alloys, the radiographic control of castings which, combined with certainty as to tensile strengths and hardness, ensure Consistency and Confidence.

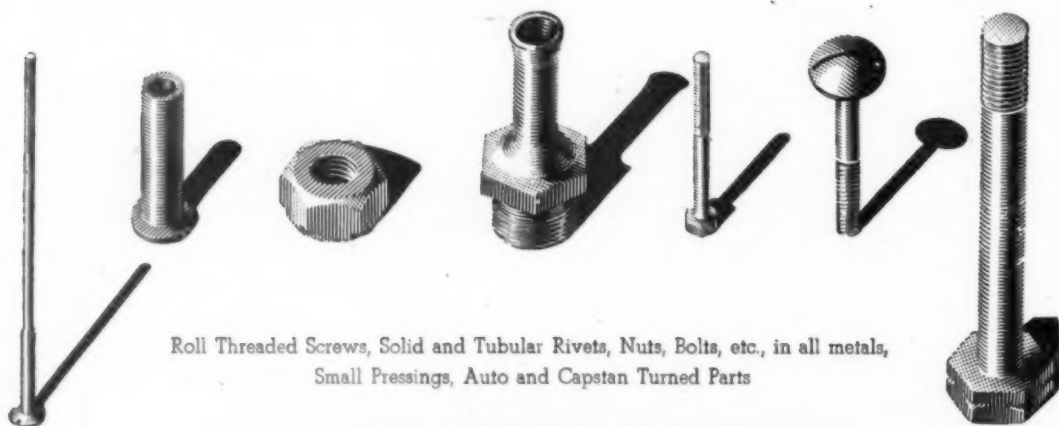
*Specialists in  
Light Metal  
Castings*

# KENT ALLOYS LTD.

HEAD OFFICES: COMMERCIAL ROAD, STROOD

## More than meets the eye

Small parts like Bolts and Screws, Rivets and Distance Pieces are not in the limelight—they do not meet the eye—but they are essential parts, and that's why the authorities have set a high standard for them. You know that's sound policy—you know that you have to use the best that is made. If you value the specialist's job that is right in every respect you will value Linreads.

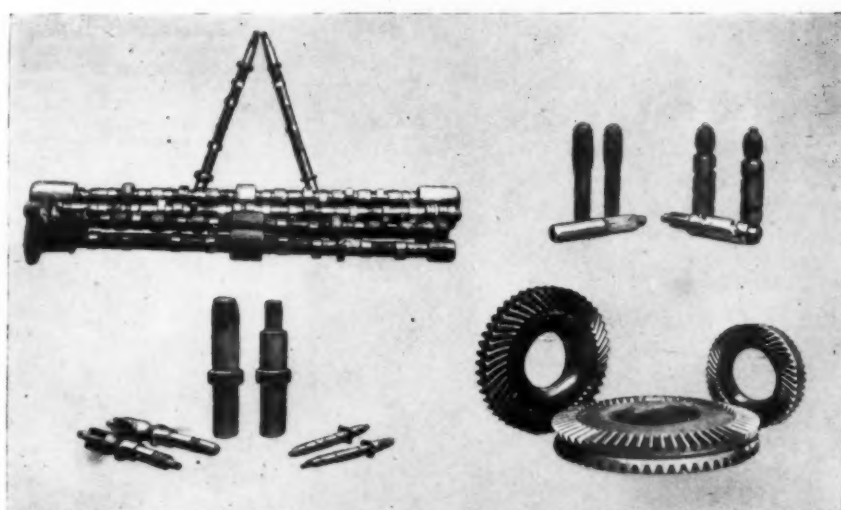


Roll Threaded Screws, Solid and Tubular Rivets, Nuts, Bolts, etc., in all metals,  
Small Pressings, Auto and Capstan Turned Parts

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LINREAD LTD., STERLING WORKS, COX ST., BIRMINGHAM, 3. Telephone: CENTRAL 6121-2-3. Telegrams: 'LINREAD'  
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**ADVANTAGES**

Easily applied. Easily removed. Self-drying. Economical in use. Uniform results. Contains no poisonous ingredients. Acid-free: therefore not injurious at high temperatures. Expensive machining after hardening avoided. Straightening difficulties eliminated or easily overcome.

**USES**

Ideal for Camshafts, Swivel Pins, Gudgeon Pins, Gears, Dies and other machined parts. Recommended for all Heat-treatment methods, including Lead-Baths and Open-Hearth.



7, HOLYROOD STREET, BERMONDSEY  
LONDON, S.E.1

HOP. 0430.



# CRYSTALLOGRAPHIC ANALYSIS OF METALS

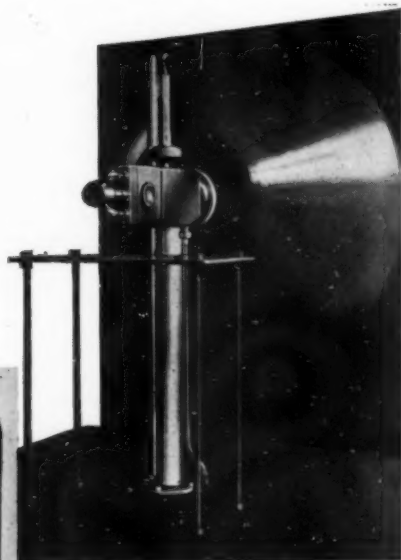


A "Metrovick" continuously-evacuated X-Ray Tube and equipment specially designed for the crystallographic analysis of materials.

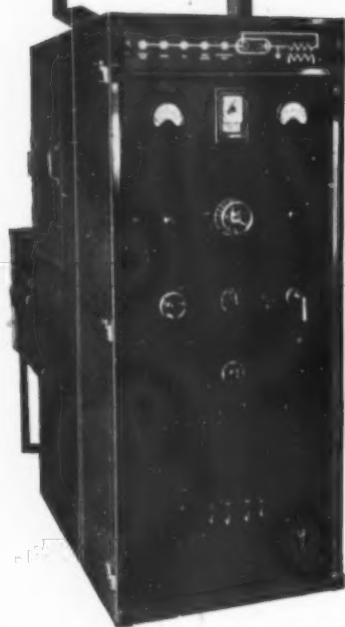
It gives information respecting the molecular structure of materials not obtainable by other means, and is of great use to the industrial research worker.

As supplied to many leading university and research laboratories throughout the country.

*Send your enquiries.*



*Close-up of X-Ray Tube with Camera Stand in position*



*View showing Control Panel mounted on the end of the X-Ray Equipment*



*The X-Ray Powder Camera*

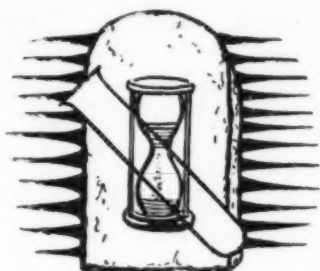


## METROPOLITAN Vickers

ELECTRICAL

CO., LTD.

TRAFFORD PARK ... MANCHESTER 17.



# MILESTONES ON THE ROAD OF PROGRESS....

..... Pyrene Metal Surface Treatment Processes first became available in the nineteen twenties with the introduction of the "PARKERIZING" Rust-Proofing Processes. Since then the following steps forward have taken place:



"BONDERIZING" for Paint Anchorage.



"PYLUMINIZING" for the protection of Aluminium.



"SPRA-BONDERIZING" for Paint Anchorage by conveyORIZED and mechanically-controlled production methods.



"D" process for "PARKERIZING" and "BONDERIZING" of iron and steel, also for treatment of zinc and cadmium surfaces or mixtures of these with ferrous metal assemblies




"PYROGRIP" Cold cement for dressing mops and bobs used for scurfing and polishing.



"PARKERIZING" for Lubrication.



War developments which have taken place in this period are at present available only to Government Factories and Contractors.



<b>PARKERIZED</b> <small>Regd. Trade Mark</small>		<b>BONDERIZED</b> <small>Regd. Trade Mark</small>
<b>SPRA-BONDERIZED</b> <small>Regd. Trade Mark</small>		
Three words meaning rust-proofed with PYRENE Chemicals		

THE PYRENE COMPANY, LIMITED, METAL FINISHING DIVISION  
Great West Road, Brentford, Middlesex

# ROBERTSON

**4-HIGH ROLLING MILL FOR STEEL  
AND NON-FERROUS SHEETS  
UP TO 56 in. WIDE**

## *Accuracy of Roll Adjustment*

Ensured by special precision type 2-motor screwdown gear.

## *Quality of Product*

Ensured by sturdy design and accurate workmanship.

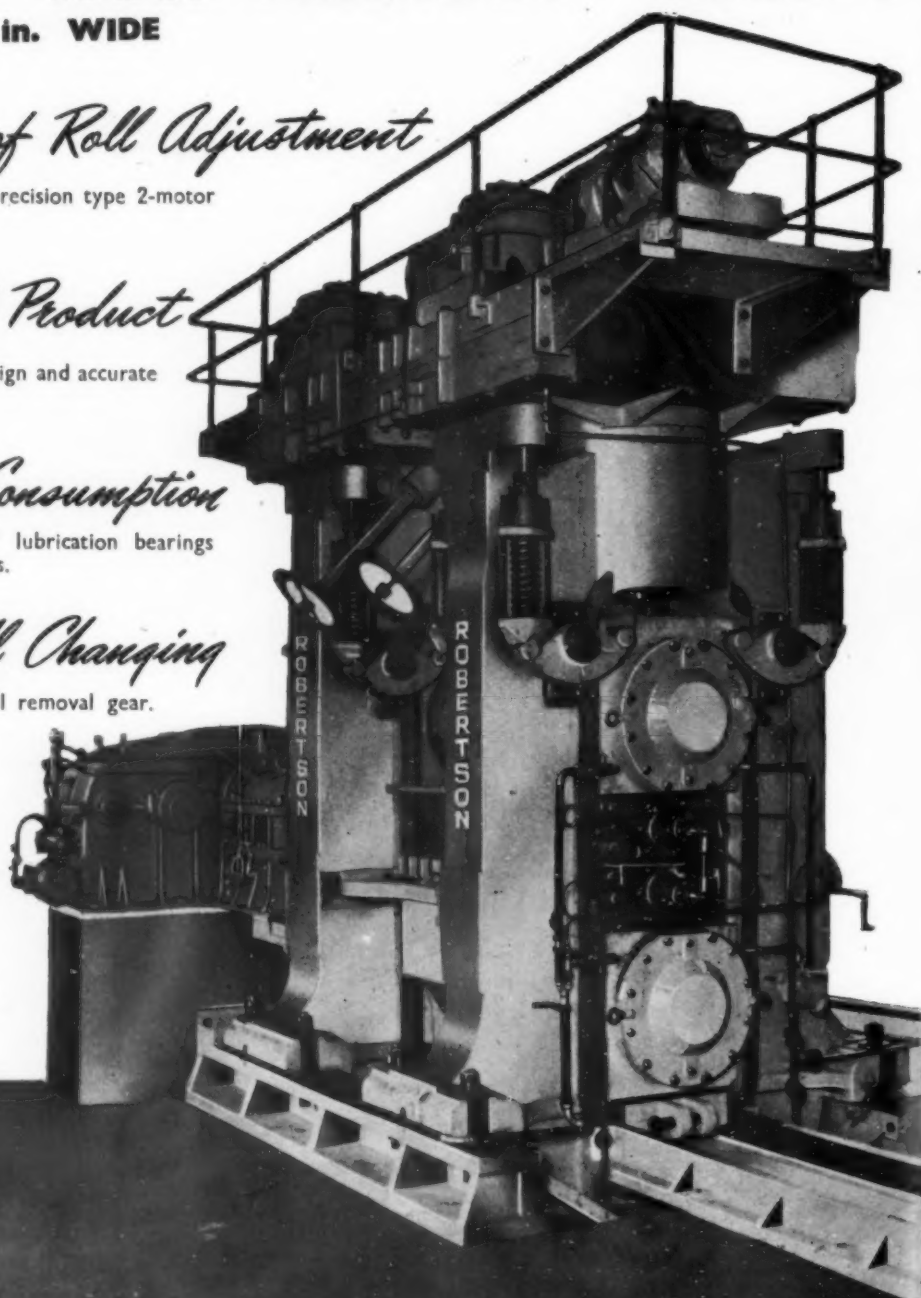
## *Low Power Consumption*

Ensured by "flood" lubrication bearings and high quality gears.

## *Quick Roll Changing*

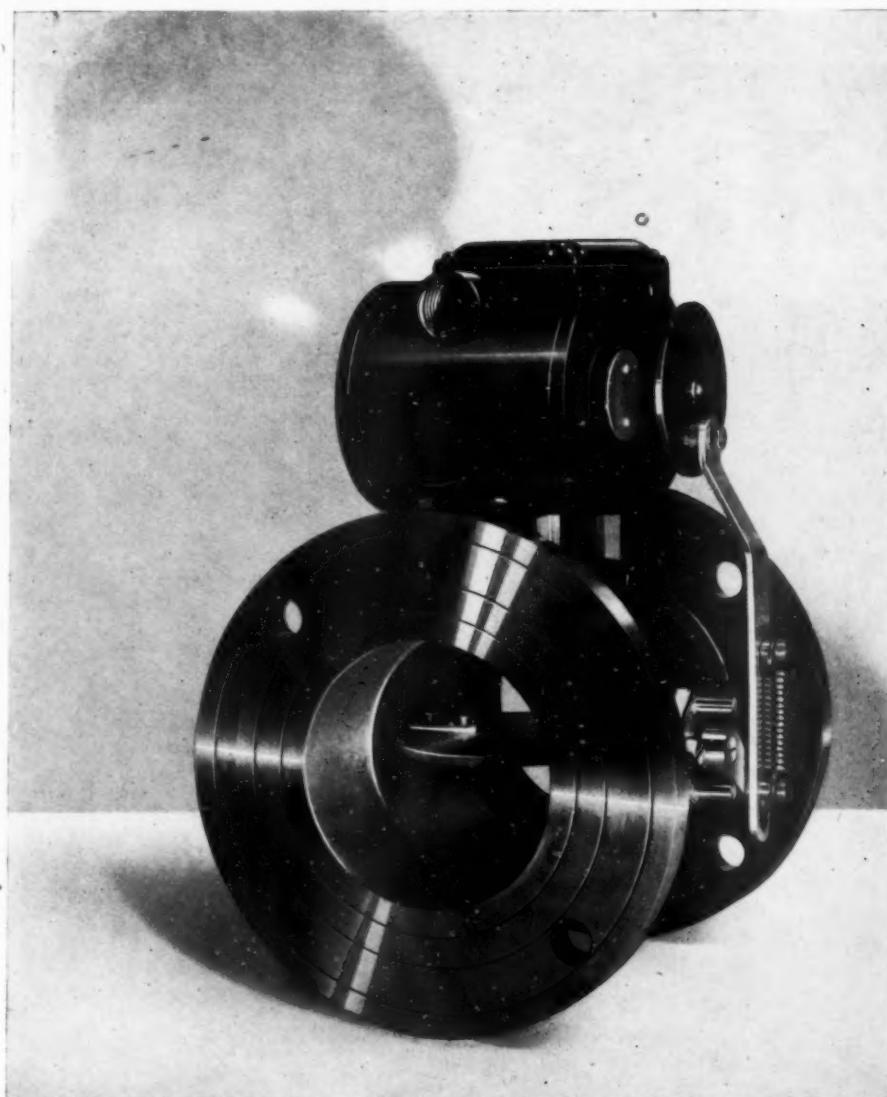
Ensured by sledge roll removal gear.

The illustration shows a Mill designed to roll sheets up to 56" wide.



**W.H.A. ROBERTSON & CO LTD**

**BEDFORD**



# **'SATCHWELL'**

## **Motorised Valves for AUTOMATIC CONTROL OF FURNACE TEMPERATURE**

*The Butterfly Valve illustrated above is constructed of high quality gunmetal and is driven by a geared electric motor giving a positive and powerful driving torque. Motorised stop valves for steam control can also be supplied.*

**THE RHEOSTATIC COMPANY LIMITED**  
**SLOUGH** **BUCKS**

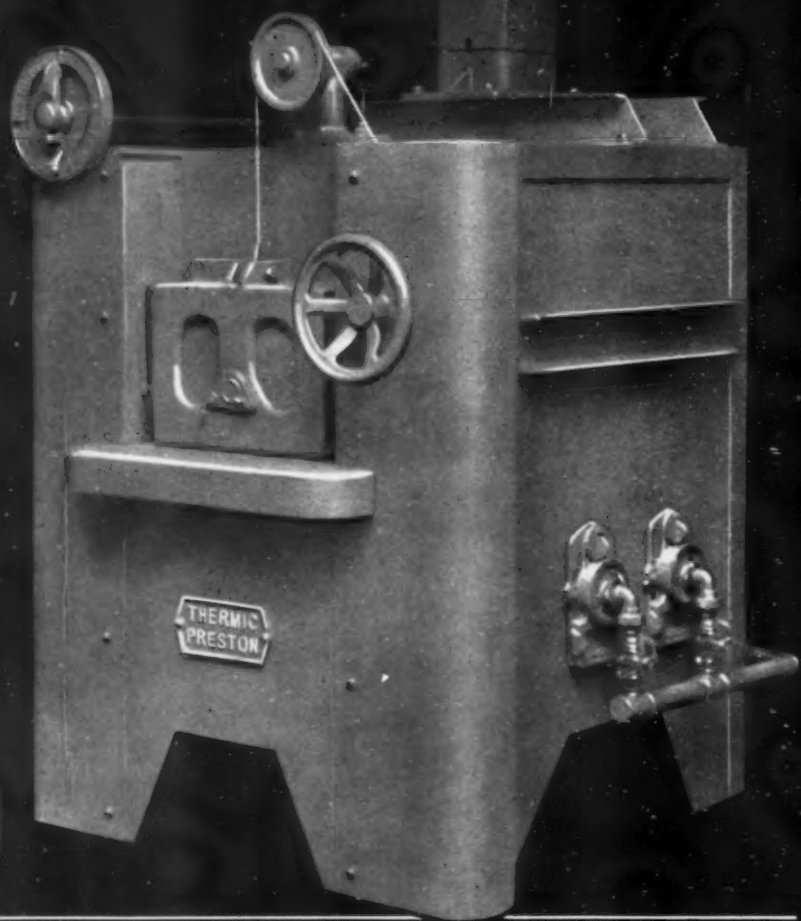
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# THERMIC

GAS FIRED SEMI-MUFFLE FURNACES



**THERMIC EQUIPMENT & ENGINEERING CO. LTD.**

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# *Sterling*

SAND & DIE CASTINGS

IN

**ELEKTRON**  
MAGNESIUM ALLOYS

**ALUMINIUM**  
NORMAL AND HEAT TREATED

"ELEKTRON" FORGINGS



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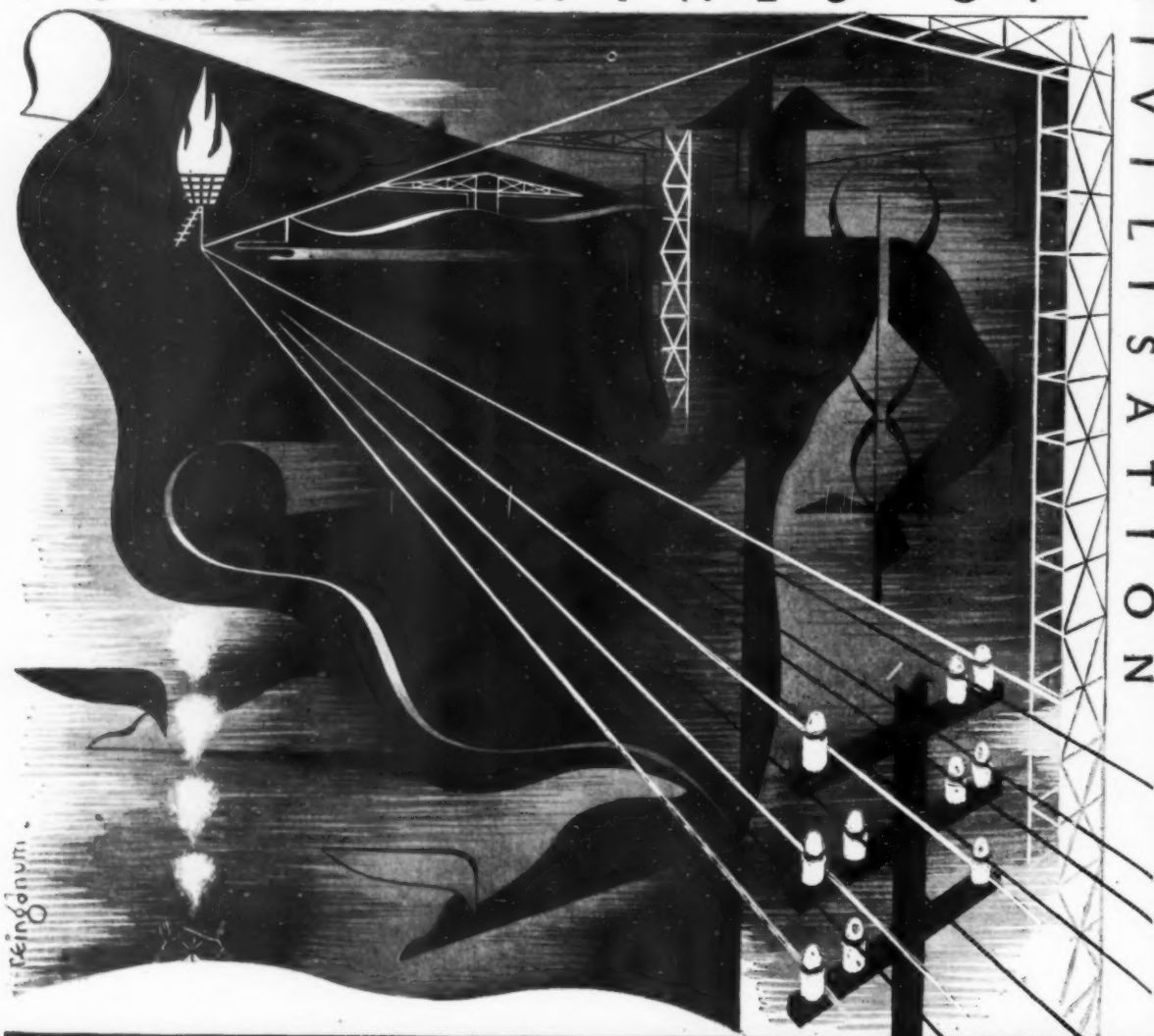
**STERLING METALS LTD**

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## FUNDAMENTALS OF CIVILISATION



## No. 7 COMMUNICATION AT A DISTANCE

Mercury of ancient mythology, was the courier of the gods flying with winged sandals to transmit their will to men.

In the dim past, tribe spoke to tribe by means of smoke signals. Then came the flaring beacons—those flames on Skiddaw which "roused the burghers of Carlisle." In days of dire peril the news of Napoleon was flashed along the coasts by semaphore.

The invention of the telegraph, telephone and radio has quickened communication between the nations of the world.

Civilisation extends through the propagation of experience, information and ideas to far distant lands. A vital part in all these complex methods of communication is played by steel.

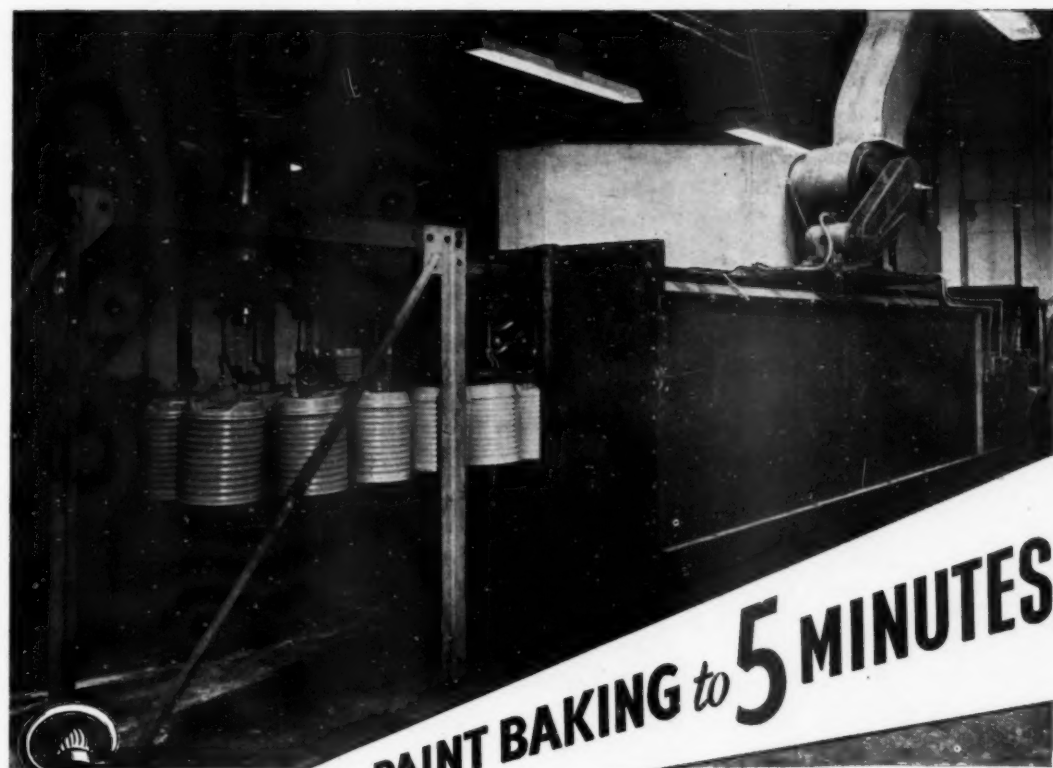


## THE UNITED STEEL COMPANIES LIMITED

STEEL, PEECH & TOZER, SHEFFIELD  
SAMUEL FOX & CO. LTD., SHEFFIELD  
UNITED STRIP & BAR MILLS, SHEFFIELD

APPLEBY-FRODINGHAM STEEL CO. LTD., SCUNTHORPE  
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THE ROTHERVALE COLLIERIES, TREETON  
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THOS. BUTLIN & CO., WELLINGBOROUGH



*Reduce PAINT BAKING to* **5 MINUTES**



## MAZDA LAMP OVENS

Baking of paint and other finishes often results in a serious bottleneck in production. Such bottlenecks can be eliminated by using infra-red lamp ovens, in which a baking time of five minutes is quite usual as against sixty minutes or more by other methods.

Baking industrial finishes by infra-red energy offers the following advantages :—

- **SAVES TIME**

Baking time is usually 10% or less of that taken by other methods.

- **SAVES SPACE**

Owing to rapid drying less space need be given up to this operation.

- **SAVES FUEL**

The system is highly efficient.

- **EASE OF ERECTION**

Oven framework need consist only of angle iron and sheet metal.

- **EASE OF MAINTENANCE**

Little can go wrong with lamp ovens.

- **REDUCES HANDLING**

The ease with which these relatively small ovens can be incorporated in the production line reduces handling to a minimum.



Write for BTH. Infra-Red Bulletin No. 1.

Complete schemes and estimates prepared by our Engineers without obligation.

THE BRITISH THOMSON-HOUSTON CO. LTD.

LAMP AND LIGHTING DEPT.

BRIDLE PATH, WATFORD JUNCTION, WATFORD.





*"Distortion never bothers me.."*

SAYS THE TOOL MAKER



**U B A S**  
THE PIONEER  
CASEHARDENING  
STEEL



**FLATHER  
STEELS**

FINE QUALITIES TO FINE LIMITS

The toolmaker who can say this and mean it, has had the bugbear of the toolmakers' existence removed from his shoulders. (If that is the right place for the wearing of bugbears. Being experts in steel and ill-versed in entomology we are not sure).

Of this we are sure, and that is, that you cannot get better behaviour out of say, the treatment furnace, than the steel-maker has put into the steel.

FLATHER STEELS standardise desirable characteristics.

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**W. T. FLATHER LTD., Standard Steel Works, SHEFFIELD**

Tel: ATTERCLIFFE 41152 (7 lines)

Do you know?

ALUMINA is dissolved from bauxite by caustic soda, producing sodium aluminate from which the pure oxide is precipitated as tri-hydrate,  $Al_2O_3 \cdot 3H_2O$ .

The main use of the hydrate is as the basic raw material of aluminous compounds such as aluminium sulphate and fluoride, and sodium aluminate.

Calcining the hydrate drives off the whole of the combined water, giving anhydrous alumina, the raw material for producing aluminium. In this form alumina is also used in the manufacture of abrasives and refractories, in the bedding of biscuit china, in the glass trade and for the manufacture of sparking plug insulators.

The anhydrous alumina may be fused in the electric arc to form extremely hard crystals, for use in high grade abrasives, refractories and plug insulators.

Two tons of bauxite are needed for each ton of pure alumina, and two tons of alumina are used to produce each ton of ALUMINIUM.

WHITE AS THE DRIVEN SNOW

THE

**British Aluminium**

CO. LTD

Temporary Head Office:

**SALISBURY HOUSE, LONDON WALL, LONDON, E.C.2**

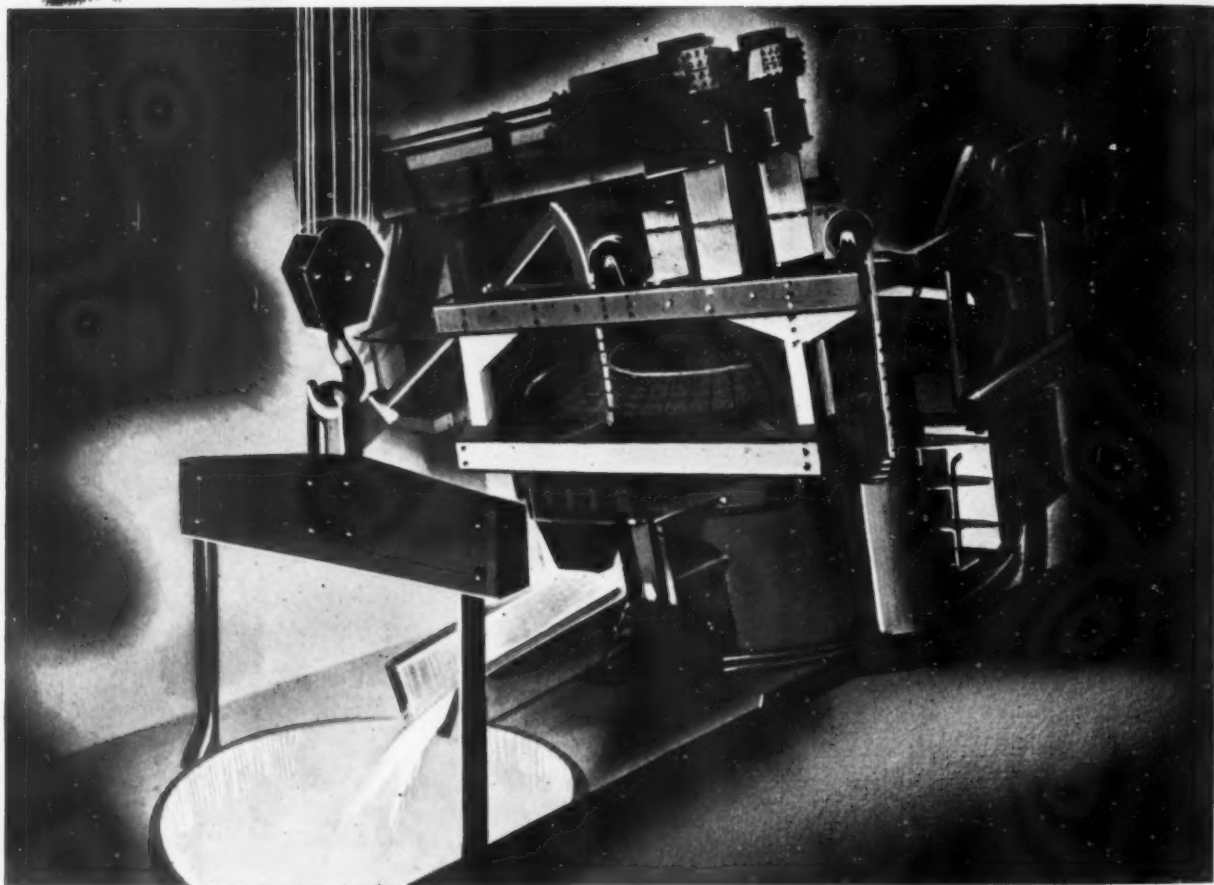
Telephone: CLErkenwell 3494

Telegrams: Cryolite, Ave, London





## IN THE VANGUARD OF PROGRESS....



The progressive development of Electric Arc Steel Furnace practice has been appreciably aided by the dependability and efficiency of Graphite Electrodes (Acheson Process) under the most rigorous conditions of operation.



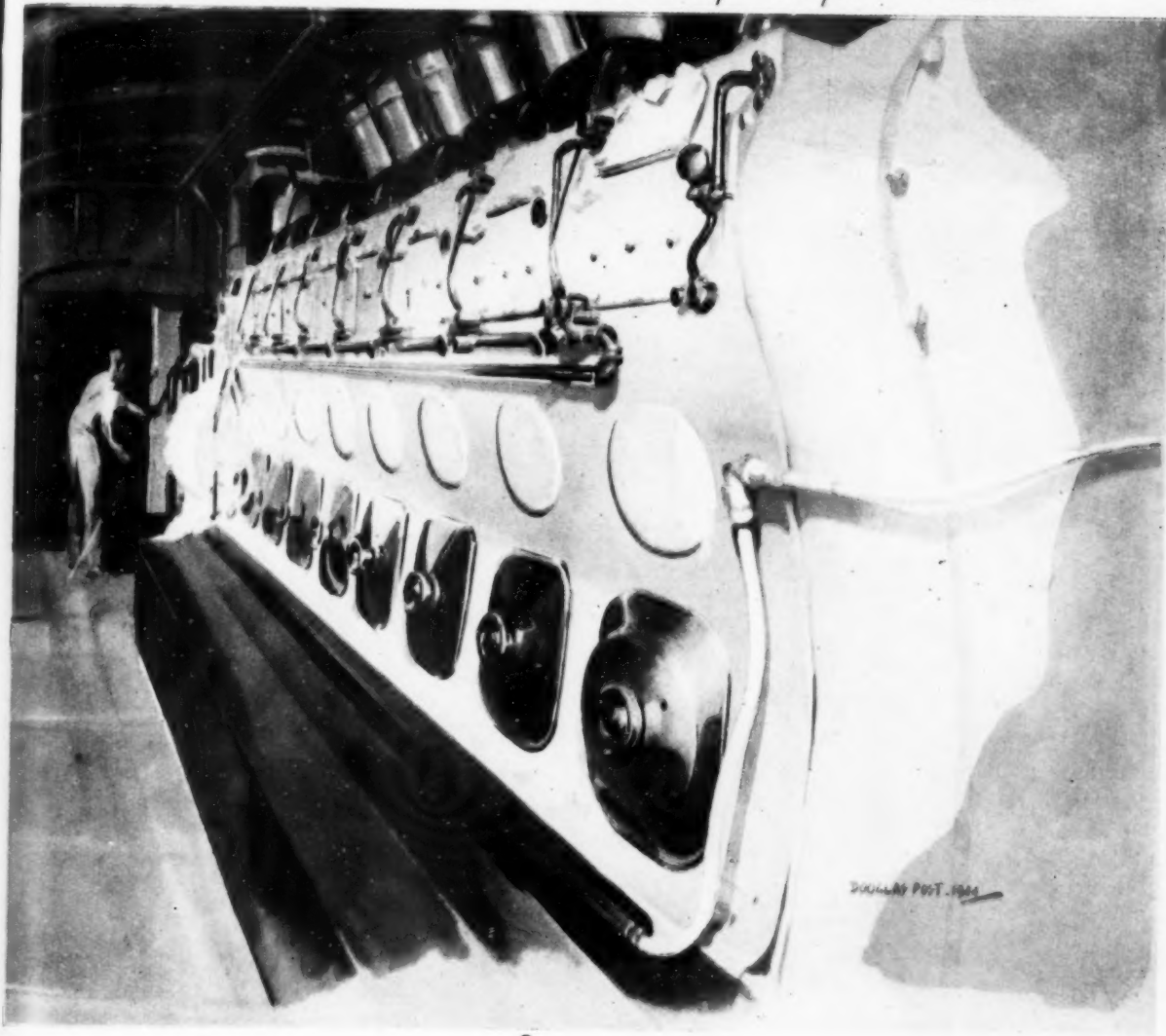
# BRITISH ACHESON ELECTRODES LTD

GRANGE MILL LANE · WINCOBANK · SHEFFIELD

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Grams Electrodes Sheffield

## *Hiduminium—The Servant of Swifter Travel*



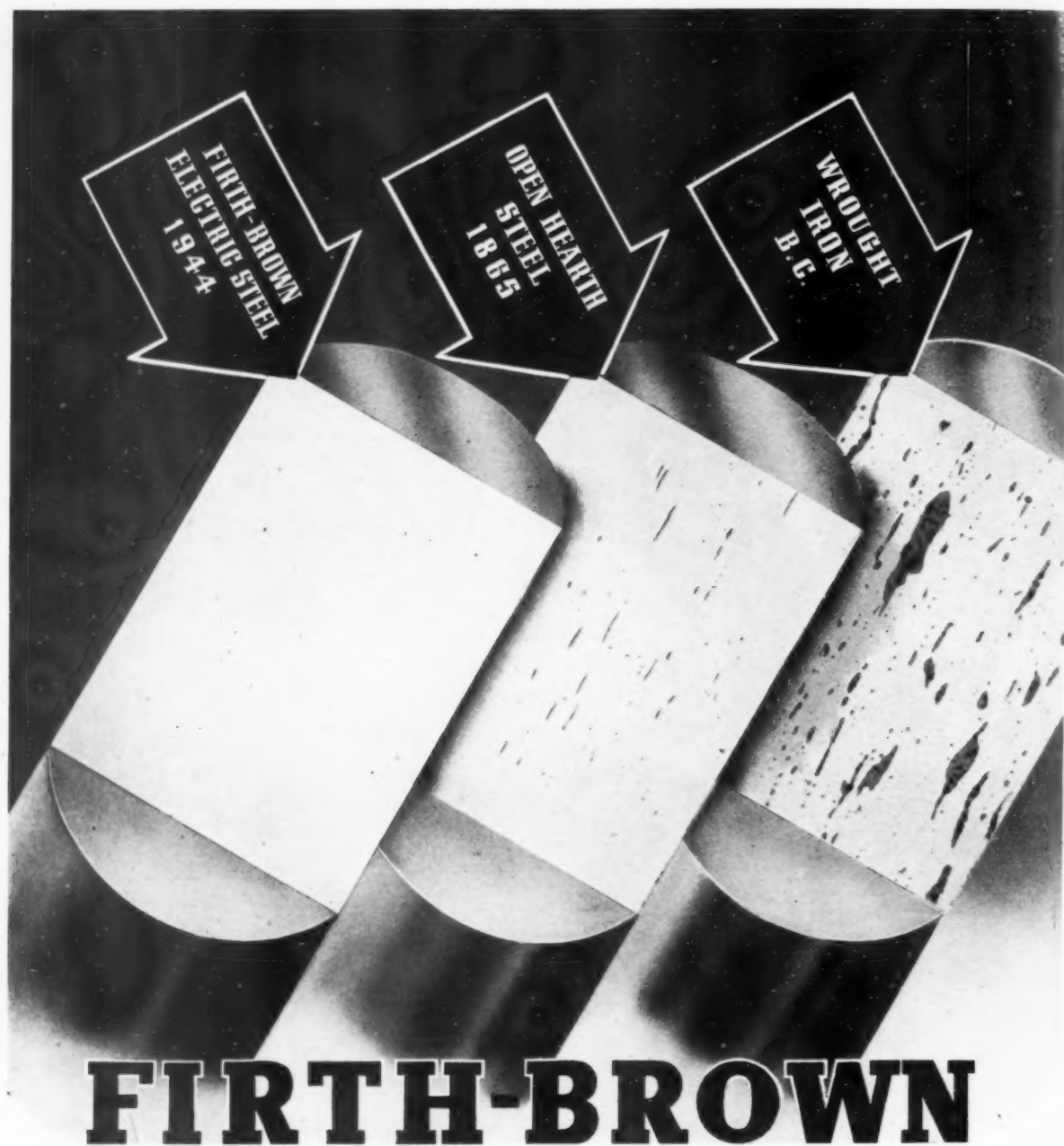
### CHANGE ON THE FOOTPLATE

The efficiency of post-war railway motive-power equipment will be greatly increased by the use of **HIDUMINIUM** aluminium alloys. The qualities possessed by these alloys, such as—high strength/weight ratio, good corrosion resistance, ease of fabrication, and ability to take pleasing finishes—will effect many changes in railway rolling stock design—from change on the footplate to a redesigning of the smallest fittings in passenger compartments. New ideas need new materials, and Hiduminium—indispensable in War—will play just as vital a part in Peace in almost every British industry and trade. Technical data is available from the Sales Department on Request.

***HIDUMINIUM***  
ALUMINIUM ALLOYS

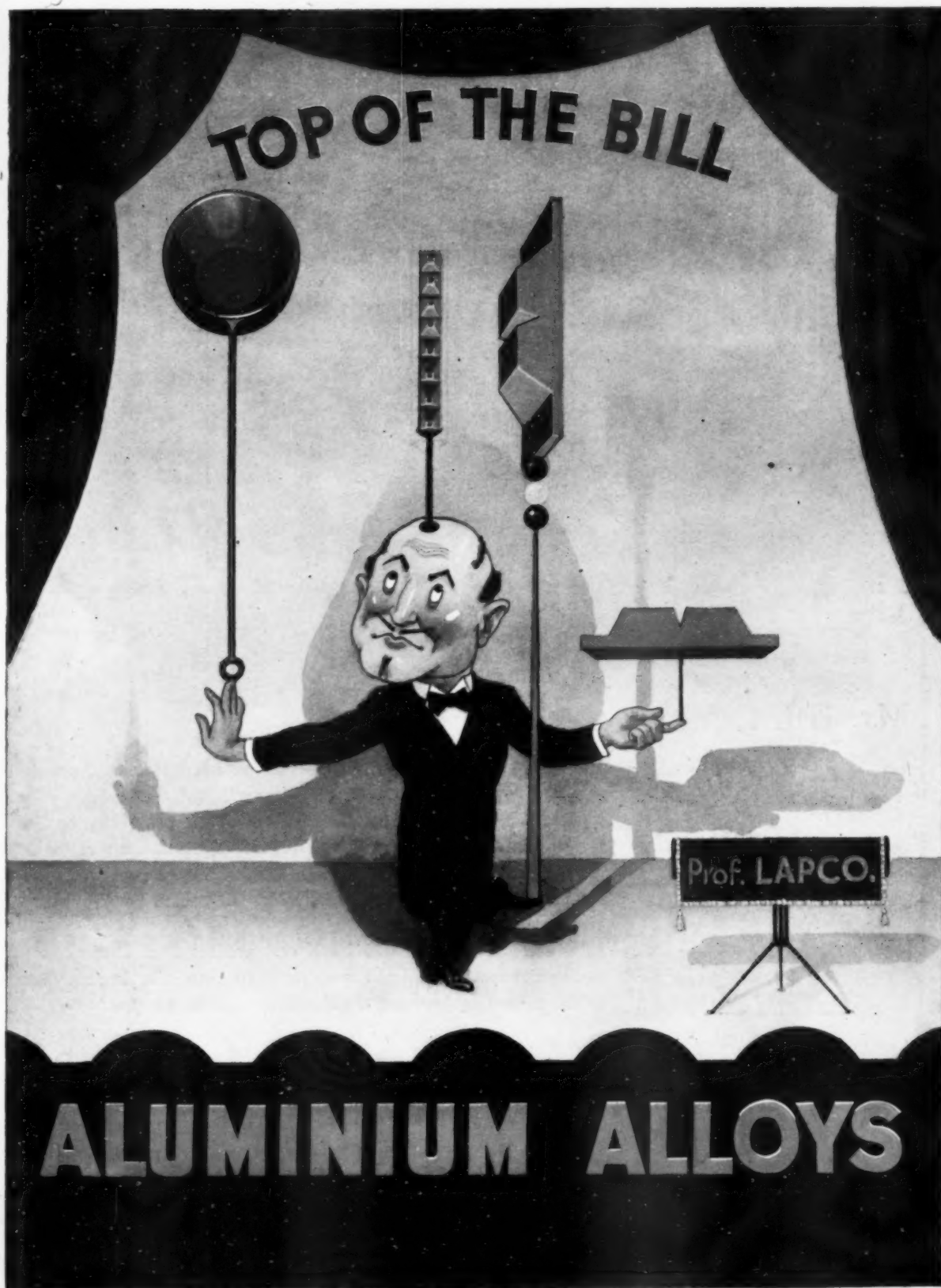
HIGH DUTY ALLOYS LIMITED & SLOUGH





Etched and magnified 100 times these examples show the progress of the Steelmaker's art. Most of the Steel user's troubles come from the unwelcome presence of "inclusions." Modern plant and modern methods remove these causes of service failure

**THOS FIRTH & JOHN BROWN LTD SHEFFIELD**





## Mr. Huntsman breaks a spring

Benjamin Huntsman, the inventor of crucible cast steel as we know it to-day, practised as a Watch and Clock Maker in Doncaster in the middle years of the eighteenth century, and the constant failure of British Spring Steel caused him to experiment and later perfect the manufacture of the fine quality steel which made him world-famous. We propose to illustrate some of the interesting episodes from Mr. Huntsman's life in this series of advertisements.

BROCKHOUSE CASTINGS LTD. now produce Steel Castings to all commercial specifications and specialise in Heat-Resisting Steels produced by the modern equivalent of the Huntsman process.



Gun Quenching Jig cast  
in Heat Resisting Steel by  
BROCKHOUSE CASTINGS LTD.

## CASTINGS IN STEEL

BROCKHOUSE CASTINGS LTD., WEDNESFIELD, WOLVERHAMPTON

Telephone : Fallings Park 31221.



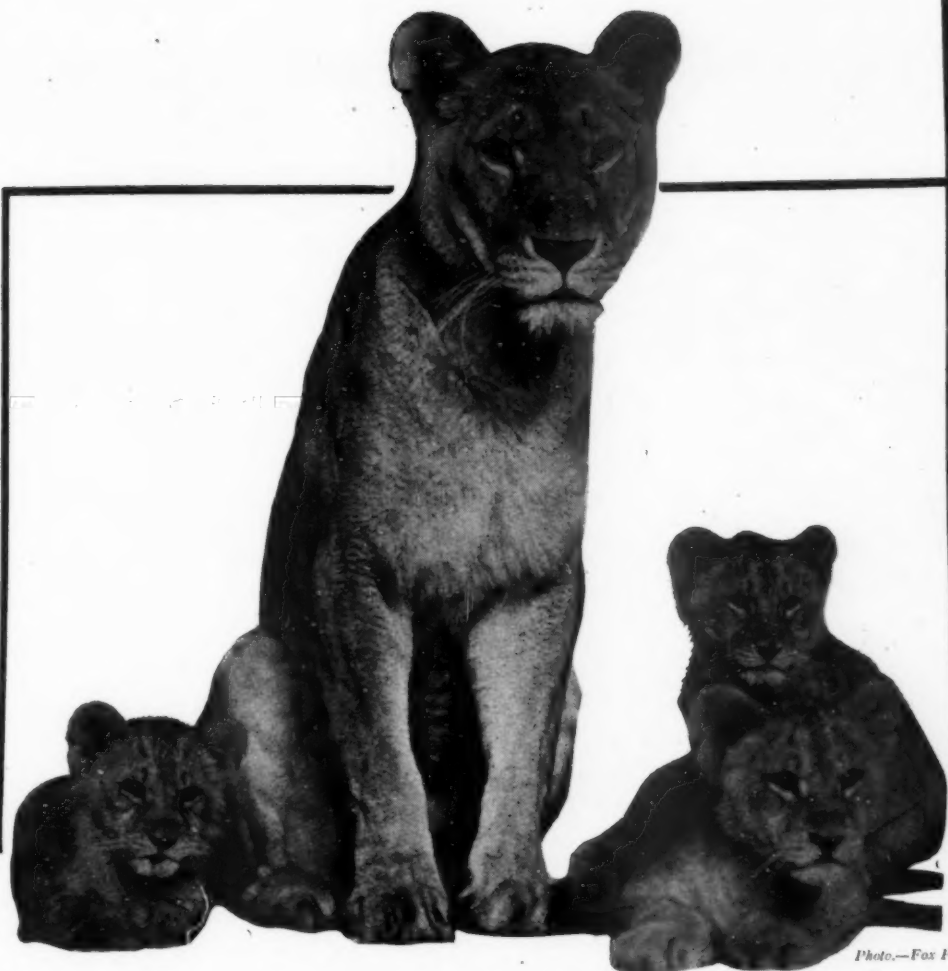


Photo.—Fox Photos

## *"Sitting up & taking notice"*

increasingly represents the attitude of many Industrial Firms, surveying post-war production, in respect to the advantages of Reynolds' Light Alloy Products.

Here are metals, strong as steel, but much lighter — that can not only help speed up the tempo of all types of machinery but effect great economy in power

— to say nothing of their high anti-corrosion properties.

It is a matter worth your serious enquiry for your post-war planning.

May we send you full particulars?

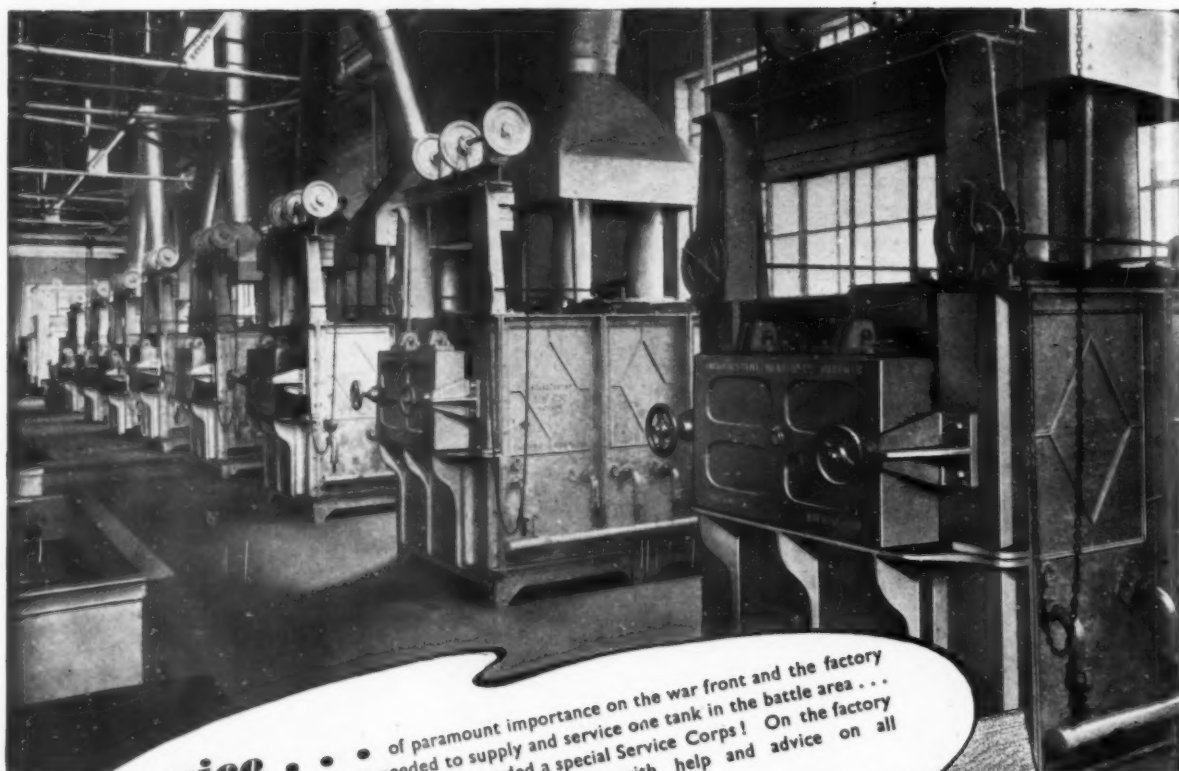
# REYNOLDS



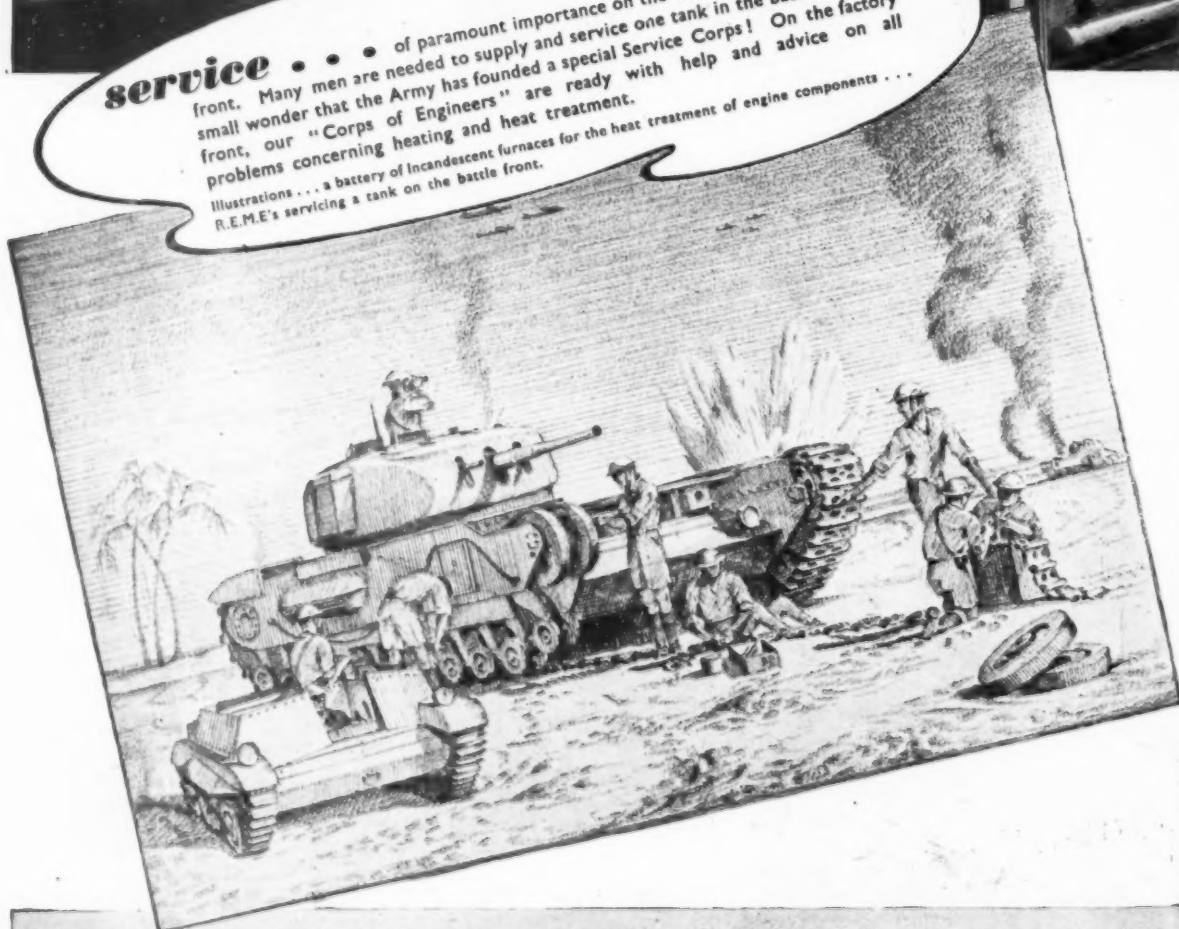
TUBES · RODS · SECTIONS · SHEET & STRIP IN "HIDUMINIUM" ALUMINIUM ALLOYS

REYNOLDS TUBE CO. LTD. & REYNOLDS ROLLING MILLS LTD., BIRMINGHAM, II.





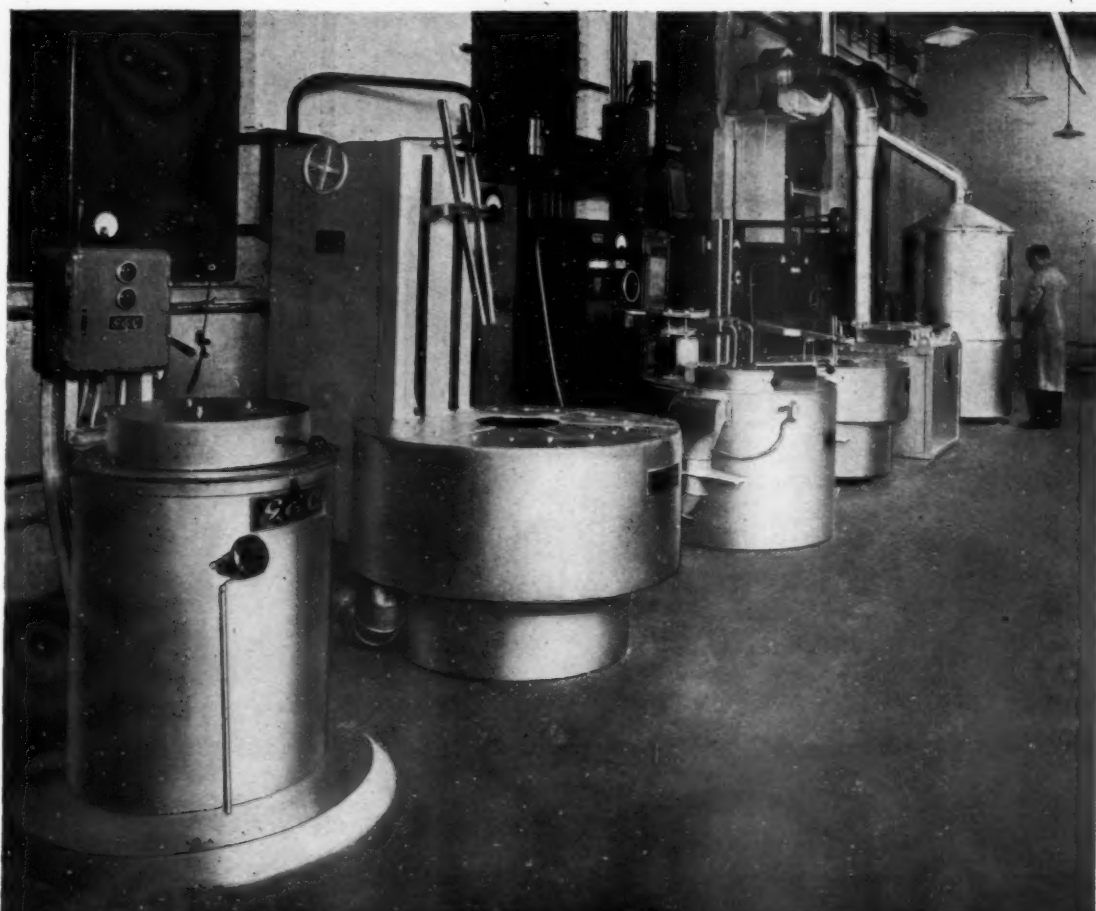
**service . . .** of paramount importance on the war front and the factory front. Many men are needed to supply and service one tank in the battle area . . . small wonder that the Army has founded a special Service Corps! On the factory front, our "Corps of Engineers" are ready with help and advice on all problems concerning heating and heat treatment. Illustrations . . . a battery of Incandescent furnaces for the heat treatment of engine components . . . R.E.M.E.'s servicing a tank on the battle front.



**Incandescent Heat Co. Ltd • Furnace Engineers • Smethwick**

# **G.E.C.**

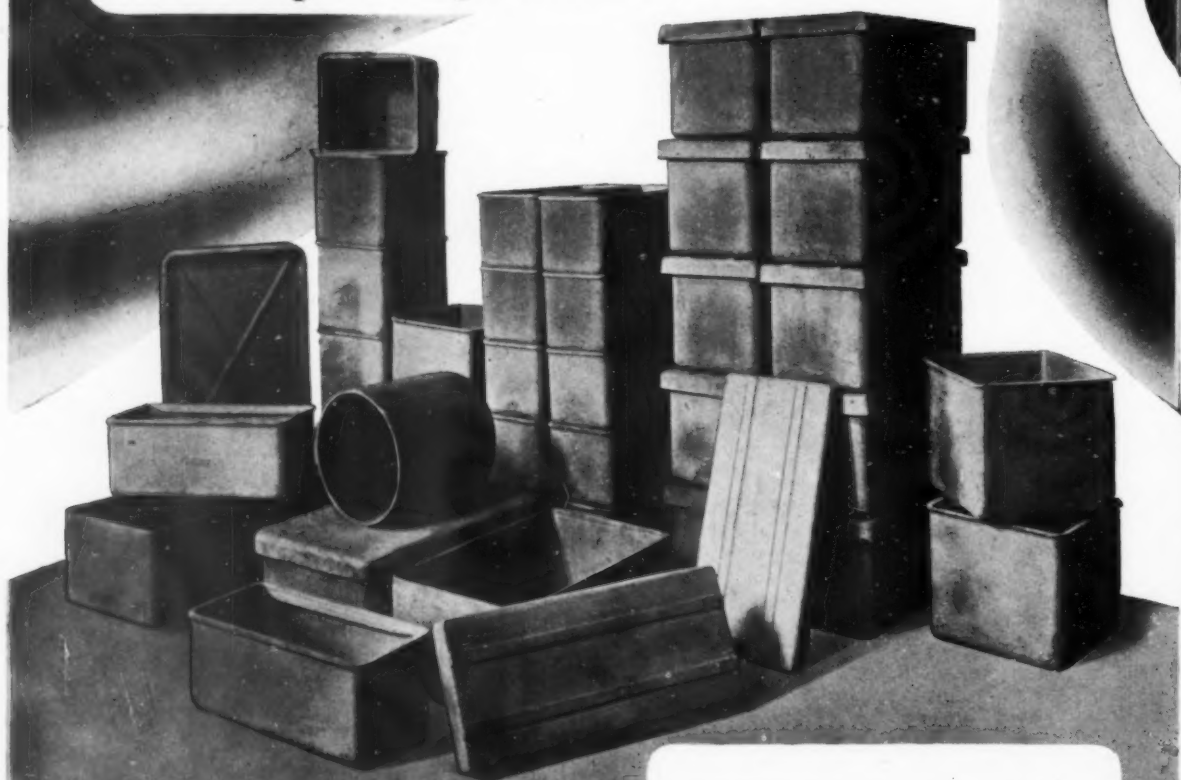
## **ELECTRIC FURNACES FOR THE TOOL ROOM**



**— preheating, hardening,  
hot quenching, carburising  
and tempering.**

..CASE-HARDENING AND ANNEALING BOXES

in  
**'PIREKS'**  
ALLOYS  
for high temperatures



**DARWINS**  
FINE STEELS  
made by craftsmen

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APRIL, 1944

METALLURGIA

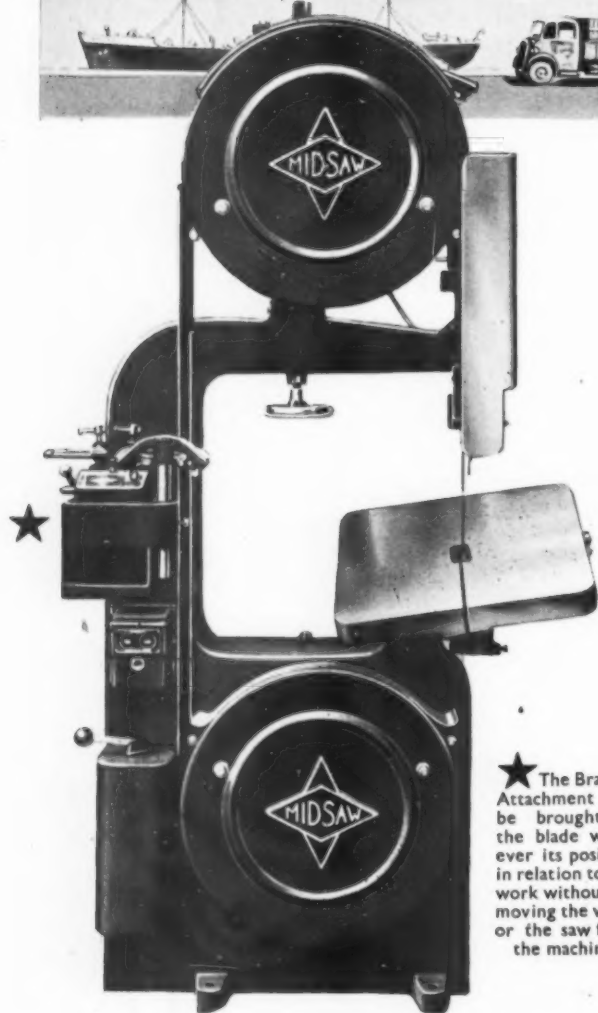


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**F**ASTER ! FASTER ! is the cry to-day, and nowhere more than in the toolroom, where accuracy cannot be sacrificed for speed. That is why and that is where MIDSAW is called the Miracle Worker. It saws and files the hardest modern metals for Dies, Press Tools, Templets, Gauges and other Toolroom jobs, both regular and irregular shapes, with a speed and accuracy impossible by any other method and it achieves this with unskilled and inexperienced operators. Are you doing jobs on a lathe, a shaper or a drilling machine that could be carried through quicker and better on a more suitable, less expensive

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A LOW  
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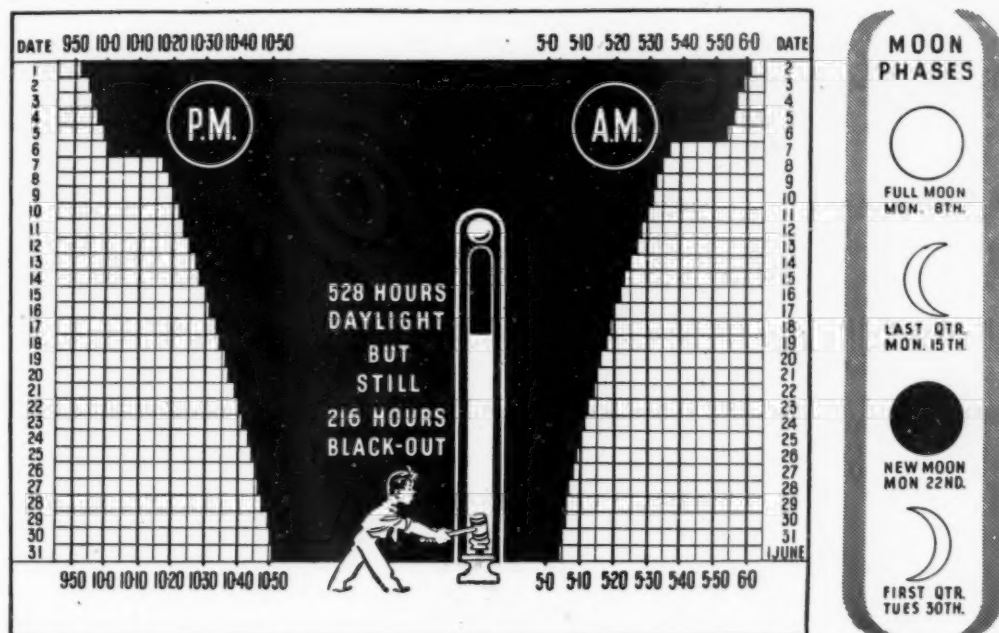
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# The Black-out closes in . . .

## BLACK-OUT CHART FOR MAY



★ Times shown are those for the London area.

Reproduced from the Nautical Almanac by permission of the Controller of H.M. Stationery Office.

Let the lengthening days of May, with more daylight in the factories, encourage and spur us to greater production efforts!

There are still, however, 24-hour shifts to be worked, and in permanently blacked-out factories artificial lighting has to be

relied upon all the time. To maintain output, to lessen the strain on workers, lighting must be adequate.

Wherever you find high standards of lighting, designed with an eye to the well-being of workers to secure improved output, there you will find OSRAM.

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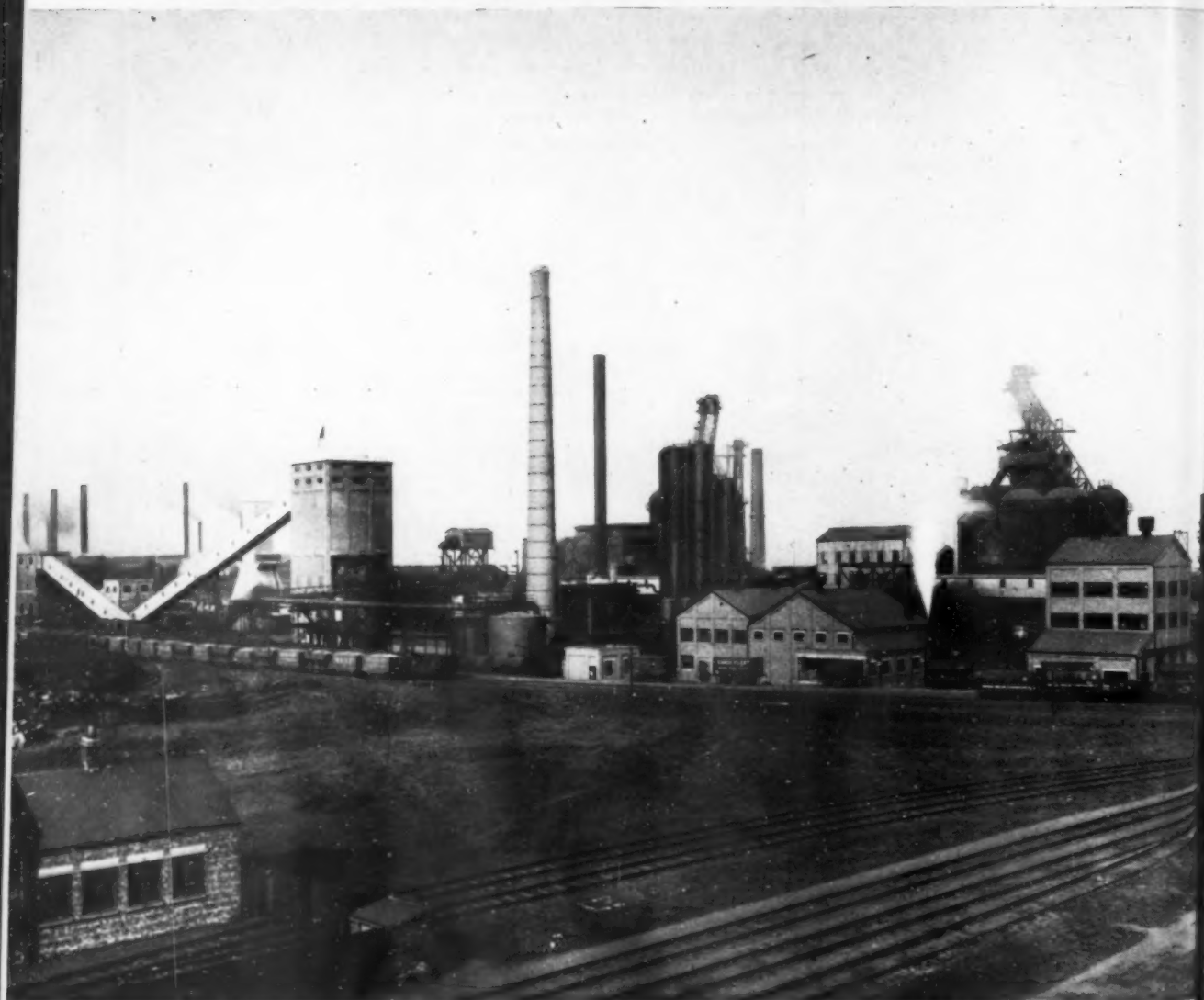


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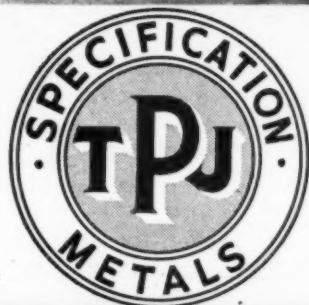
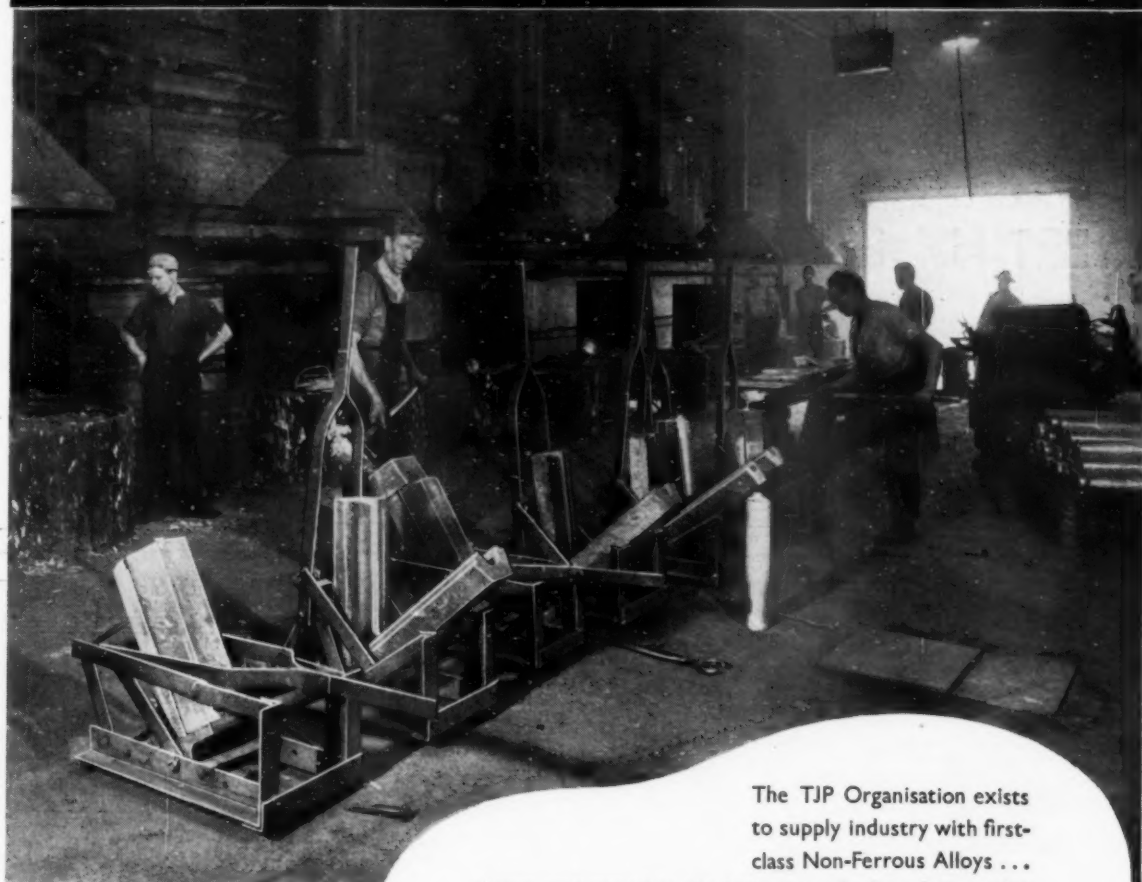
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always maintained at the highest level of quality, so that their reliability has come to be well known and appreciated by a large circle of users in a wide variety of trades. In the happier days of Peace TJP Products will undoubtedly be in greater demand than ever and will make a real contribution to the betterment of that new world we are all striving for.

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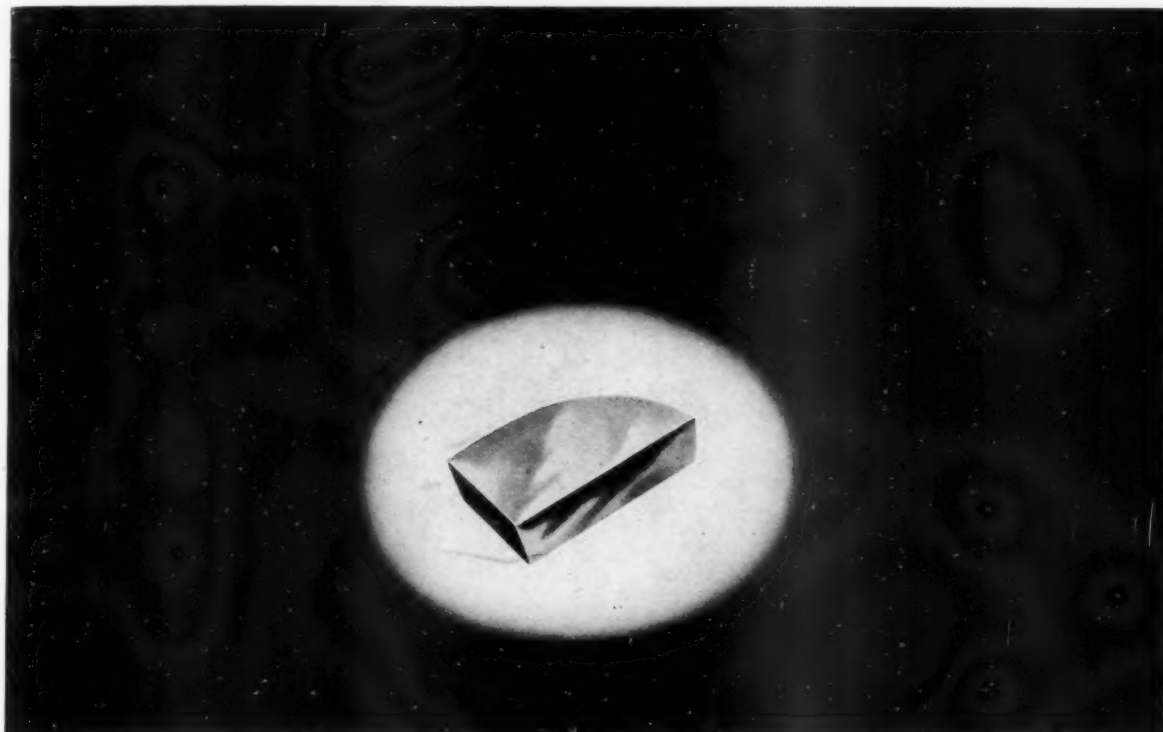


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Not without good reason have Wimet Tips become the standard by which all others are judged, for since we, the original pioneers in the manufacture of carbide tools in this country, produced Wimet Brand Tool Metal from which Wimet Tips are made, it has remained absolutely unsurpassed, the best tool metal ever used. Making for greater speed and accuracy as they do, Wimet Tips cannot fail to have a most stimulating effect on production, and their use will prove a very effective economy, due to their long working life between regrinds. Wimet, the finest and most durable of all, are the only tips to use on your cutting tools. Our specialists are available to assist you in the application of Wimet to your production problems, and there is a grade of Wimet Tool Metal for every machinable material.

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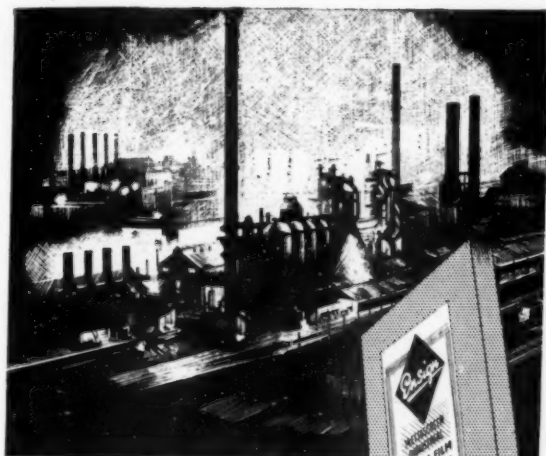
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tools of  $\frac{3}{8}$ " square up to 1" square can be tipped using a welding powder. The maximum electrical input is approximately 12 K.V.A.



### THE TIPPING OF MILLING CUTTERS

The use of simple fixtures which we can supply permits the tipping of Inserted Tooth Milling Cutters from  $\frac{1}{4}$ " wide up to 1" wide with Carbide or Deloro Stellite. High Speed Steel inserted Tooth Cutters from  $\frac{3}{8}$ " up to  $\frac{3}{4}$ " wide can similarly be made.

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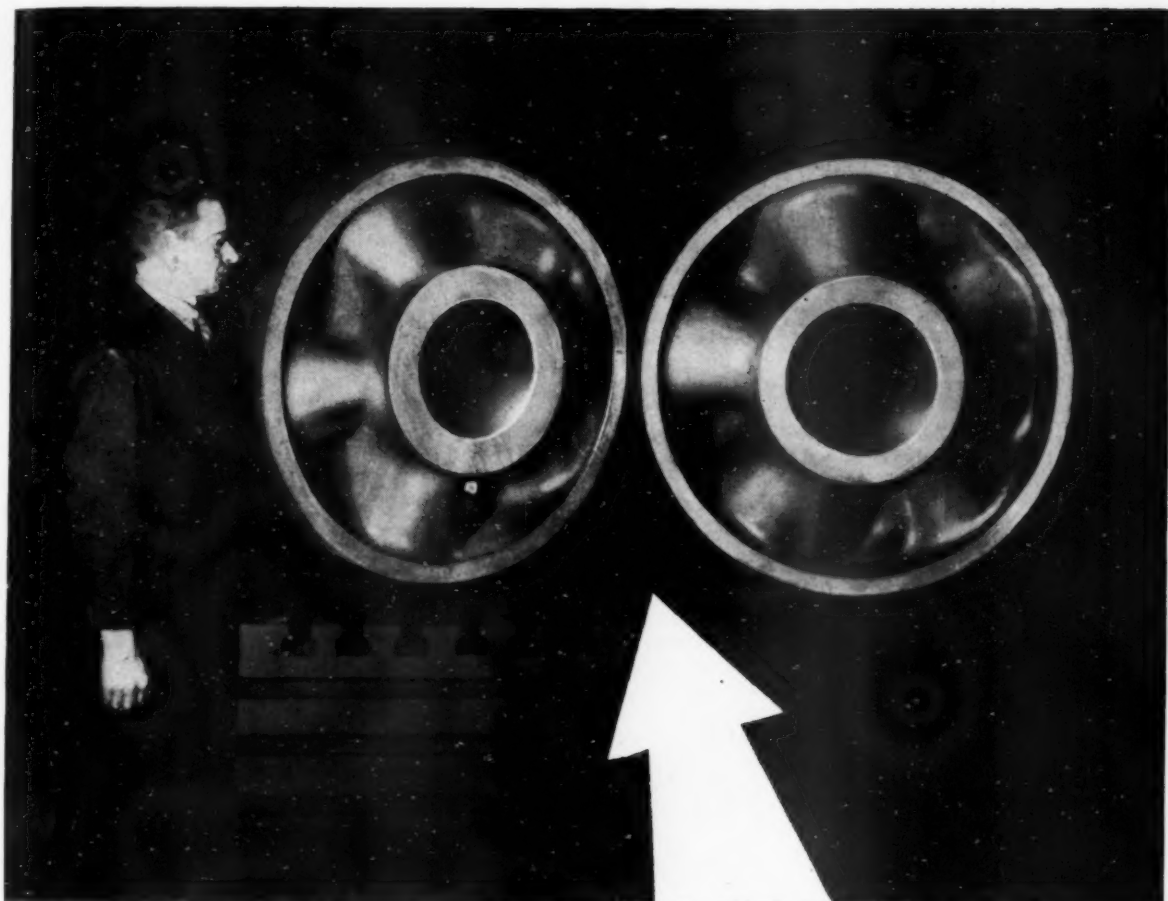
➔ 12" scale. For routine temperature measurements anywhere. For checking other instruments or thermocouples in the plant or laboratory.

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Elektron Magnesium Alloy Pulleys  
35" diameter as used on double-acting  
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# Non-Destructive Testing of Non-Ferrous Semi-Finished Metal Products by New Magnetic Induction Methods

By W. Schirp

**T**HE magnetic induction method for the inspection of non-ferrous metals depends on the fact that the apparent resistance of a coil fed with high-frequency alternating current and surrounding the specimen varies with the dimensions and electrical conductivity of the latter. The method is primarily suited for tubes, rods or profiles of nominally constant cross-section which can be passed through the coil. Flow rates as high as 1 m./sec. can be maintained through the apparatus, which normally is provided with two test coils forming the opposite arms of a Wheatstone bridge. An E.M.F. of sonic frequency is applied, and the out-of-balance current after amplification can be observed on a cathode ray oscillograph and will operate an electronic relay as soon as certain limiting values are exceeded.

When testing for consistency of dimensions or constitution (hardness or heat-treatment, type of alloy, etc.) the specimen under investigation passes through one of the coils whilst the other surrounds a stationary reference sample. Dimensional errors are separated from those due to heat-treatment, etc., by changes in phase displacement of the cathode ray record. The sensitivity of the inspection is not sufficient to record cracks or other internal faults (inclusions).

Such faults are detected by passing the specimen through both coils in succession, the coils being placed in close proximity to each other. Under these conditions, changes in dimension or constitution of sample (unless they are abnormal) will affect both coils equally, each crack or fault, on the

other hand, giving rise to two discontinuities in the record (a crack smaller than the longitudinal dimension of the coils is recorded twice as it passes through the two coils whilst for longer cracks the beginning and end of the fault is recorded). It is obvious that by duplicating the circuits and recorders and employing three search coils spanning the specimen whilst a fourth surrounds the standard, the fault testing can be carried out simultaneously with inspection for dimensions and heat-treatment.

In most cases of semi-finished products, the latter inspection need not be carried out over the whole length of the specimen. Thus in the apparatus developed by Heinkel for Dural tubes the checking for dimensions and heat-treatment against a standard is carried out over the first 20 cm., whilst the testing for flaws is carried out over the remaining length. Only one set of electronic recorders is thus required, the coils only being switched in or out as required.

The test process is completely automatic and does not depend on visual observation, special electronic relays being provided which automatically mark faulty sections of the tubes as they pass through the apparatus. Further relays ensure that only specimens fulfilling the specification are passed on to the works, the rejects being further sorted depending on whether the material or dimensions are at fault.

A great advantage of the apparatus is the high speed of operation (over 1 m./sec.), and the absence of skilled attention. It is stated that prior to its

installation, numerous cases arose where faults either escaped detection or were only noticed after an appreciable amount of fabrication had been carried out on the product.

From *E.F.Z.*, vol. 64, No. 31/32, Aug. 12, 1943, pp. 413-414. By courtesy of R.T.P.S., Ministry of Aircraft Production.

## Iron-Plating

By W. B. Stoddard, Junr.

**D**EPOSITION of ductile iron from chloride solution was reported by Kasper in 1937, who arrived at the conclusion that relatively soft, ductile iron can be deposited from a bath containing 5 N ferrous chloride and 0-10 N hydrochloric acid at a temperature of 222° F. (105½° C.) and a current density of 186 amp. per sq. ft. (2,000 amp./m.<sup>2</sup>).

However, an improved chloride iron-plating solution has been developed in which grain size is controlled by the addition to the solution of relatively small amounts of manganese chloride, and pitting is eliminated by the use of the proper wetting agents. The improved iron-plating solution contains 200-500 grms. per litre of FeCl<sub>2</sub>·4H<sub>2</sub>O, plus 3-5 grms. per litre of MnCl<sub>2</sub>·4H<sub>2</sub>O and about 1 gm. per litre of gardinol W.A. powder. The temperature range over which this solution will produce heavy, fine-grain ductile deposits is broad, running from 150° to 220° F. (65½-104½° C.). The pH range is 1.5 to 2.5, with an optimum at about 2.0. The cathode-current density range broadens as the temperature increases. At 160° F. (71° C.) the maximum current density is of the order of 50 amp. per sq. ft. (540 amp./m.<sup>2</sup>). In uncontaminated solutions the current efficiency is above 95%. No ventilation is necessary. Many materials, however, will cause embrittlement and gassing in this solution.

From *Chemical and Metallurgical Engineering*, December, 1943.

**M**ETALLURGICAL CONSULTANTS offer their services on all metallurgical work covering Founding, Forging, Extrusions, Heat-treatment, Welding and Protective Processes.—51, Russell Road, Horsell, Woking.

**R**ESearch METALLURGIST, preferably with knowledge of engineering, required by well-known North Country firm specialising in the use and heat-treatment of high carbon and alloy steels. Age 27 to 37. Knowledge of the wire trade useful. Must be a good mathematician, capable of conducting own industrial research. Salary £450 to £600 per annum, according to education, experience and character. Applicants should write for application form, which must be returned by April 29th, 1944, to the Ministry of Labour and National Service, Central (Technical and Scientific) Register, Room 432, Alexandra House, Kingsway, London, W.C.2, quoting F.2019XA.

**T**HE Proprietors of the Patent No. 461716 for Improvements in Metallic Screens, Stencils and the like and Formation thereof are desirous of entering into arrangements by way of licence and otherwise on reasonable terms for the purpose of exploiting the same and ensuring its full development and practical working in this country. All communications should be addressed in the first instance to Haseltine Lake and Co., 28, Southampton Buildings, Chancery Lane, London, W.C.2.

**T**HE Proprietors of the Patent No. 515043 for Improvements in the Production of Metallic Screens by Electrodeposition are desirous of entering into arrangements by way of licence and otherwise on reasonable terms for the purpose of exploiting the same and ensuring its full development and practical working in this country. All communications should be addressed in the first instance to Haseltine Lake and Co., 28, Southampton Buildings, Chancery Lane, London, W.C.2.

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invented by Currans and protected by their Patents have enabled the Company to make a valuable contribution to the war effort of this country and the Company has been gratified by the notable success which their plants have achieved.

In common with other manufacturers in this country Currans' inventions have been entirely at the disposal of the Government during the war period and until the war is over Currans' inventions will continue to serve the country. When, however, hostilities cease, the Company intends to exercise its rights to prevent infringement of its Patents.

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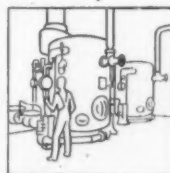


## Jet propulsion 150 B.C

WAS HERO OF ALEXANDRIA the first inventor with a sense of humour? In 150 B.C. or thereabouts, he seems to have designed a turbine toy as a form of comic relief from siege catapults and other 'secret weapons'. A little premature, of course. In fact the basic principle of his 'whirling aeolipile', with its hollow bronze ball rotated by the expulsion of jets of steam, was never put to practical use until the invention of the Parsons turbine in 1884. But steam had been making headway along other lines. The 18th Century saw Newcomen's crude piston engine and Watt's master patent raise steam-power to the status of prime mover number one in world industry.

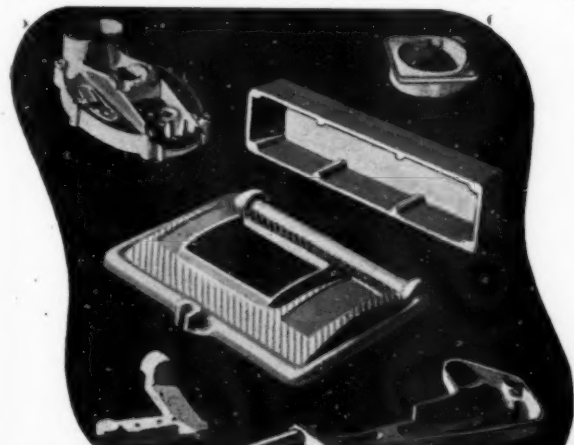
In spite of progress, however, the industrialist was little better off in one respect than Hero of Alexandria. Always the engine improved . . . never the fuel—until the Gas Industry introduced fuel on tap. Today the constant trend towards automatic fuel feed and thermostatic control brings gas newer and bigger jobs in modern industry. Today the industrialist can plan for automatic continuous production on the basis of quick, cheap, reliable fuel . . . fuel on tap, capable of simple, flexible, automatic control . . . clean fuel, which lends itself to use in nearly every modern industry through a wide range of compact and hygienic labour-saving equipment.

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INDUSTRIALIST  
APPRECIATES THE  
VALUE OF GAS



Gas equipment is only available now for priority work, but industrialists planning for the post-war period can benefit from wartime experience and achievement.

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Meantime, we keenly appreciate the courtesy and understanding implied by the consistent support of our many trade friends. We are proud to continue in Service and, subject only to National requirements, will strive to maintain normal peacetime efficiency.

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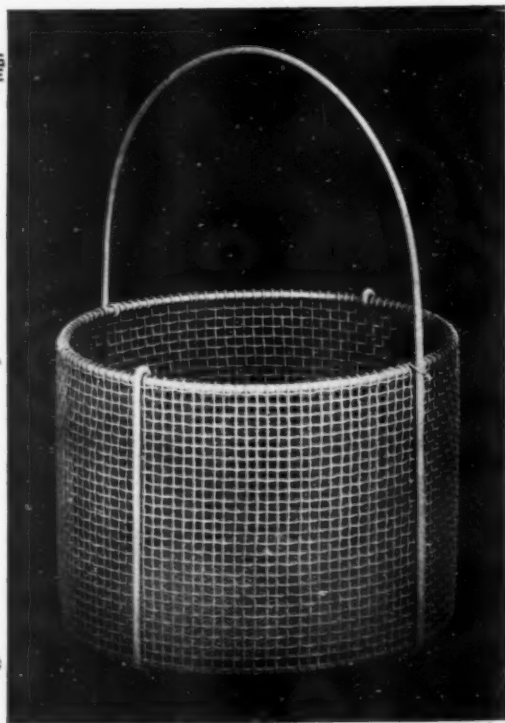
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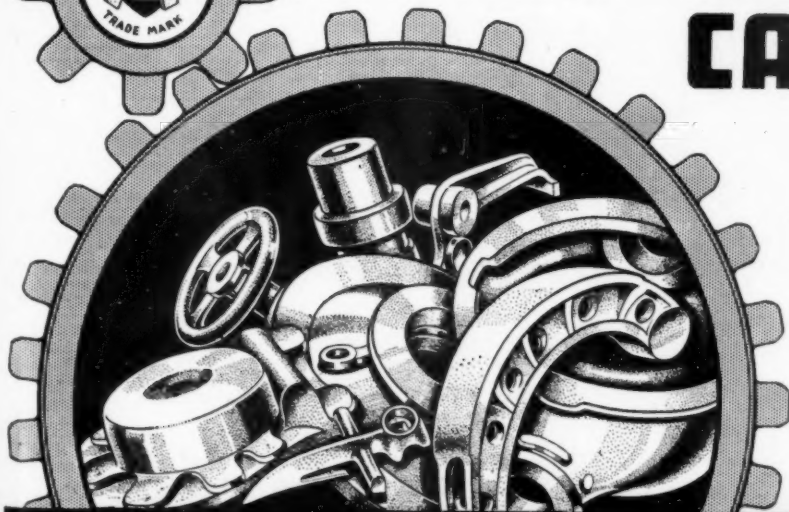
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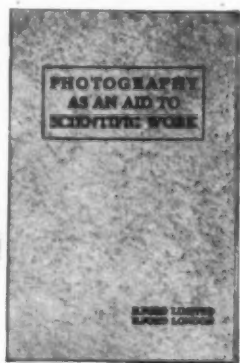
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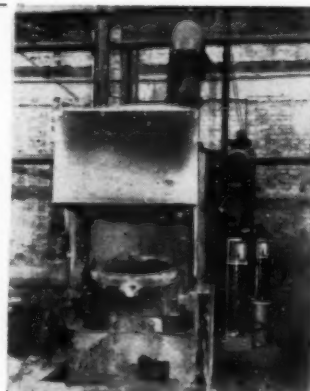
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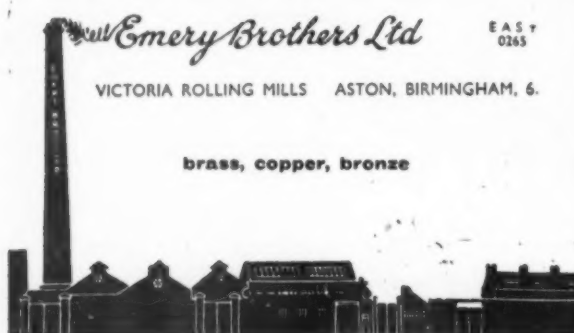
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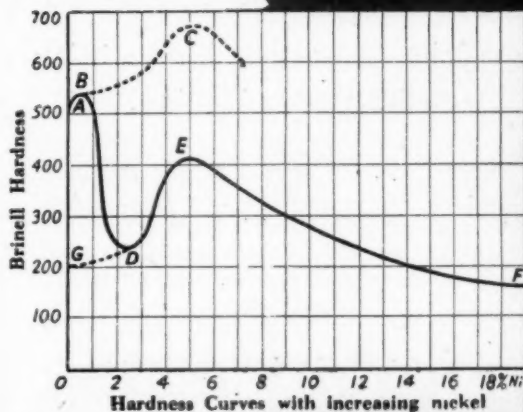
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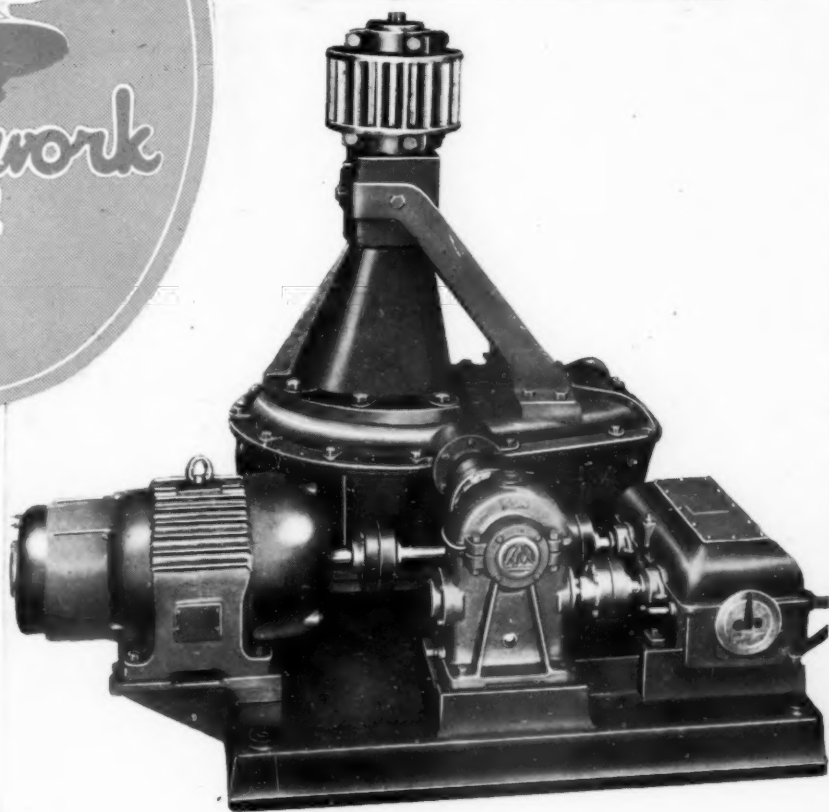
APRIL, 1944

METALLURGIA

# THE BEST WORM GEAR



*Completely enclosed, Dust-Proof and Oil immersed,  
impervious to dirt, moisture, acid fumes, or other  
unfavourable operating conditions.*



**T**YPICAL combined Double Worm and Spur Drive for steel works plant. Ratio of reduction 2160/1 with speed variation by P.I.V. infinitely variable speed gear to 6480/1 total ratio.

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Worm Reduction Gears are carefully constructed and rigidly tested. Conservative rating enables them to withstand heavy over-loads and provide a smooth even drive with large reduction ratios.

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April 1944.

# METALLURGIA

*"I'm making twice as many  
as I did two years ago"*



"I've been making these parts for two years. At first I got out about 130 or 150 a day. Then they gave us a different kind of steel to make them with—with magenta ends if that means anything—grand stuff. I've never made less than 300 parts a day since then—with better finish and longer tool life.

This new stuff is British and it comes from several Works.

I never want the old stuff again, and none of the other girls do. You should hear the tool room boys—they speak as though we were little angels—but this steel is the real angel."

